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# POWER, HEATING AND VENTILATION

## A TREATISE FOR DESIGNING AND CONSTRUCTING ENGINEERS, ARCHITECTS AND STUDENTS

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By CHARLES L. HUBBARD, B. S., M. E.
Consulting Engineer, Boston

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PART I.

## BOILER ROOM EQUIPMENT

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*FIRST EDITION*

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# PREFACE

The matter contained in the following pages had its beginning in a pocket notebook, which in turn served as a basis for numerous articles which have appeared in the technical press from time to time.

Occasional calls for reprints of these articles led the author to select those having the most practical value and to combine with them sufficient new material to form a treatise covering the design, construction and management of power and heating plants.

The subject of power is treated more especially from the steam side, with sufficient space devoted to electrical matters to enable the engineer to intelligently arrange his steam plant with reference to the requirements of electric lighting and the distribution of electric power.

No attempt has been made to cover central station work; only plants of small and medium size being considered, similar to those found in manufactories, office buildings and institutions.

The subject of heating is taken up quite fully, and includes the warming and ventilating of all classes of buildings, from a small, furnace-heated dwelling to buildings with central plants of the largest size.

Special thanks are due to the editors of various magazines for permission to use material which has appeared over the author's name in their publications.

As many of the chapters have been rewritten from several published articles upon similar subjects, it has been impossible to give suitable credit in the text, and for this reason it has seemed best to give the references by chapters, as follows:

*American Architect,* Part III., Chapters 5, 6, 7, 8, 14, 15.

*American Electrician,* Part I., Chapters 2, 3, 5, 6, 7, 8, 9, 10, 11, 13, 14, 16; Part II., Chapters 1, 3.

*American Artisan,* Part III., Chapter 4.

New York Dec. 6, 1911 $4.25 (3 vols)

*Domestic Engineering,* Part III., Chapters 10, 11.
*Electrical World,* Part II., Chapters 1, 2.
*Electrical Review,* Part I., Chapter 16; Part II., Chapter 9.
*Engineering Review,* Part I., Chapter 12; Part III., Chapters 4, 12.
*Engineering Record,* Part III., Chapter 15.
*Heating and Ventilating Magazine,* Part III., Chapters 2, 3, 13.
*Machinery,* Part I., Chapter 5; Part III., Chapters 10, 11.
*Metal Worker,* Part III., Chapters 7, 8, 9, 10.
*Power,* Part I., Chapters 3, 9; Part III., Chapter 10. (From "Boiler Power for Elevators," "Boiler Power for Refrigeration," "Fans for Mechanical Draft.")
*Science and Industry,* Part I., Chapter 3; Part II., Chapters 1, 3.
*Steam Engineering,* Part I., Chapters 2, 6, 11, 14; Part II., Chapters 1, 3, 4; Part III., Chapter 12.
*The Engineer,* Part I., Chapters 1, 2, 3, 4, 5, 6, 7, 8, 10, 11; Part II., Chapters 3, 4.

Acknowledgment is also due for the courtesy extended by the authors and publishers of the following books of reference:

*Heating and Ventilation of Buildings,* by Carpenter, data on heat, design of aspirating coils and electric heating.
*Steam Boilers, and Mechanical Engineers' Pocket Book,* by Kent, data on heat, steam, boiler horse power, boiler design, boiler furnaces, chimneys, mechanical draft.
*Steam Power Plants,* by Meyer, data on chimneys and feed piping.
*Mechanical Draft,* B. F. Sturtevant Company, data on boiler horse power, chimneys, mechanical draft and fans.
*Steam Boilers,* by Peabody and Miller, data on boiler horse power, boiler design, corrosion and chimneys.
*Furnace Heating,* by Snow, data on the design of furnace heating plants.
*Ventilation and Heating,* B. F. Sturtevant Company, data on forced-blast heating and ventilation.

Matter upon the care and management of alternators in Part II., Chapter 9, has been kindly furnished by the Allis-Chalmers Company.

Thanks are due to Mr. F. R. Still of the American Blower Company for valuable data and suggestions in the preparation of the matter on fans, and to Mr. L. R. Nash for reviewing that portion relating to electricity and electrical equipment; also to the makers of various kinds of apparatus shown, for the use of tables and cuts.

It has been the intention of the author to give credit in every

case where due, but if through any oversight this has not been done, it will be considered a favor to have such oversight reported in order that it may be corrected in future editions.

This also applies to such errors and omissions as are sure to appear in the text of the first editions of a book of this kind.

CHARLES L. HUBBARD.

*Boston, Mass.*

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## CHAPTER I.

### HEAT.

As the various effects of heat enter so largely into the subjects treated in the following pages, a brief discussion of its nature and some of its more important properties may be of assistance to the reader, by fixing clearly in his mind the exact meaning of the terms most frequently used.

Heat is recognized by the bodily sensation of touch, and by means of this we are able to judge roughly of the temperature of an object. The terms heat and cold are relative only, and when we speak of a body as being hot or cold we mean that its temperature is higher or lower than that of some other body with which it is compared.

*Theory of Heat.*—There have been many theories in regard to the exact nature of heat, but the accepted one at the present time is that of molecular vibration. It is thought that heat is a vibration of the molecules of which a body is composed, and that the degree of heat, or temperature, depends upon the velocity and amplitude of the vibrations.

Bodies in general expand when heated. This is explained by the fact that the molecules when in motion force each other apart, so that the whole body occupies a greater space than before.

Solids melt and liquids turn to gas when heated to certain temperatures. This means that when the vibrations become sufficiently violent the molecules are pushed apart to such an extent that their attraction for each other is greatly lessened and the character of the substance is changed through lack of stiffness or stability. Heat can be produced by hammering or distorting a

body in any way. Hammering a body naturally shakes its molecules, and thus increases their agitation.

The weight of a body is not changed by increasing or decreasing its temperature. The movement of a body makes it neither lighter nor heavier, therefore the vibration of its molecules does not change their weight.

Heat will pass from one body to another when one is "hotter" than the other. This naturally follows because a body which is vibrating vigorously will give some of its motion to one having a less motion, when brought in contact with it.

From the above, we see that the present theory accounts for the various phenomena connected with heat, and further, has enabled people to make predictions which have been verified by experiment.

### Temperature and Its Measurement.

*Temperature.*—The intensity of the heat in a body, that is, the velocity of vibration of its molecules, is called the temperature. This, however, does not indicate the *quantity* of heat which it contains. For example, a small bar of iron may be heated to a white heat and still contain a much smaller quantity of heat than a larger bar at a lower temperature.

*Thermometers.*—The temperature of a body is determined by comparing it with some substance whose intensity of heat is known. The simplest way of doing this is to use a substance the volume of which changes a definite amount with the addition or removal of a given quantity of heat, and always has the same volume for the same degree of temperature. A substance having the above property is placed in a glass bulb, to which is connected a tube of small bore. As heat is applied to the bulb the substance expands into the tube. Marks are then made at the height at which the substance stands when it has a certain degree of heat. In order to make the comparison, we place the bulb of the tube, which is called a *thermometer,* in contact with the body whose temperature we wish to know, and then note the height of the substance within the tube. We say two bodies have the same temperature, when no heat will pass from one to the other if they are

placed in contact. Therefore the reading of a thermometer indicates the temperature of the body with which it is in contact, but cannot give the *quantity* of heat it contains.

Mercury is commonly used in thermometers, although air, water, alcohol and other substances are often employed.

*Fahrenheit Scale (F.).*—The scale most frequently used in this country is known as the Fahrenheit scale. The graduations in this case are obtained by noting the position of the mercury column when the bulb is placed in melting ice, and again when placed in steam which is being evaporated under atmospheric pressure. This difference in the heights of the column is divided into 180 equal parts, called degrees. The freezing point of this scale is marked 32 degrees, which makes the boiling point $32+180=212$ degrees above zero.

*Centigrade Scale (C.)*—In the French system the Centigrade thermometer is used. The freezing point on this scale is marked zero, and the boiling point 100.

*Methods of Conversion.*—As the difference between the freezing and boiling points on the Fahrenheit scale is divided into 180 degrees, and on the Centigrade scale into 100 degrees, it follows that 1 degree C. $=180\div100=1.8$ degree F., and 1 degree F. $=100\div180=0.55$ degree C.

Zero on the Centigrade scale is at the freezing point, and on the Fahrenheit scale it is 32 degrees below the freezing point. Therefore, to change the Fahrenheit scale to Centigrade, we must first subtract 32 and then multiply the remainder by 0.55.

The methods of conversion may be represented by the following equations, in which C. is the reading in degrees Centigrade and F. the reading in degrees Fahrenheit.

$$\text{C.}=0.55\times(\text{F.}-32)$$
$$\text{F.}=(1.8\times\text{C.})+32$$

*Example.*—Reduce 60° F. to the Centigrade scale. $(60°-32)\times0.55=15.4°$ C. The reason for this is evident because 60° F. is $60-32=28°$ above the freezing point and 1° F. $=0.55°$ C.; then $28°$ F. $=28\times0.55=15.4°$ C.

In like manner readings on the Centigrade scale can be changed

to the Fahrenheit scale by first multiplying by 1.8 and then adding 32 to the product.

*Absolute Temperature.*—The volume of a "perfect gas" at a temperature of zero Centigrade varies $\frac{1}{273}$ of its volume for a change of one degree in its temperature, when under constant pressure. Assuming this to hold true for other temperatures, the volume of a perfect gas will become zero, or *nothing*, when cooled to a temperature of 273° below zero. This point is called the *absolute zero* and corresponds to 460.66 degrees below zero on the Fahrenheit scale.

To reduce Centigrade readings to absolute, add 273.

To reduce Fahrenheit readings to absolute, add 460.66, or 461 in round numbers.

*Example.*—Plus 10° F. $= (461 + 10) = 471°$ absolute, and minus 10° F. $= (461 - 10) = 451°$ absolute. The absolute zero is only an imaginary condition, but absolute temperatures are often used in making computations where ratios occur.

### General Definitions for the English System.

*Unit of Heat.*—The unit of heat is taken as the quantity required to raise the temperature of one pound of pure water one degree at its point of greatest density, which is at about 39° F.

The quantity of heat required to raise one pound of water through successive degrees is not quite constant, but increases slightly as the temperature rises. For all practical purposes, however, we may neglect this, and define a heat unit, or British Thermal Unit (B. T. U.) as the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit.

*Latent Heat.*—When heat is applied to a body and it passes from a solid to a liquid state, its temperature remains practically constant during the process. The heat which disappears during this change is called the *latent heat of fusion,* and represents the work done in tearing apart the molecules of the substance. When the body solidifies, this heat is given back again. The heat required to change a liquid into a gas is called the *latent heat of evaporation,* or *vaporization.* The heat necessary to melt ice into

water, and then evaporate the water into steam, are familiar examples of the above.

*Specific Heat.*—The quantity of heat required to raise the temperature of a body one degree is called its ***thermal capacity.*** The thermal capacity of a pound of pure water is one B. T. U. and is greater than that of any other known substance. The thermal capacity of a given weight of any other substance, compared with an equal weight of water, is called its ***specific heat,*** and is always less than 1. We may thus define specific heat as the quantity of heat, expressed in thermal units, necessary to raise the temperature of one pound of any substance one degree.

*Conduction.*—The transfer of heat between two bodies which are in contact is called ***conduction.*** When this transfer takes place between different parts of one continuous body, it is called ***internal*** conduction. When it passes from one body to another it is known as ***external*** conduction. If one end of an iron bar be held in the fire, the other end soon becomes heated by conduction. If a piece of wood were used in place of the bar, the end in the fire would burn, and but little heat would be transferred to the other end. Thus we see that some substances are good conductors of heat while others are not.

*Convection.*—We know from experience that lighter solids or liquids will float upon a heavier liquid. When a portion of a liquid is heated and expands, it rises to the surface because it is lighter, or rather because the cooler liquid surrounding it falls to the bottom of the vessel and forces the lighter liquid upward. Currents set up in this manner are called ***convection*** currents. Convection also takes place in gases.

*Radiation.*—We have learned that in a heated body the molecules are supposed to be in violent agitation. The motion of these vibrating molecules or particles is communicated to the surrounding ether, and transmitted by it with great rapidity in the form of waves. Heat transmitted in this manner is called ***radiant*** heat, and the process is called ***radiation.***

Radiant heat travels in straight lines through a uniform medium, and the radiation is equal in all directions. The heat from a fireplace or steam radiator is radiant heat, and passes through the air

to the walls of a room which absorb it. As these become warm the heat is given off to the surrounding air by conduction and is diffused throughout the room by convection. A certain amount of heat is also absorbed by the air directly from the radiator in the same way.

*Thermodynamics.*—That branch of science which considers the relation between heat and mechanical work is called ***thermodynamics.*** It deals with the numerical relation between the quantity of heat used and the amount of work done.

We have already seen that heat is produced by hammering or distorting a body. Other examples of the generation of heat by work are found in the bearings of machinery, cutting tools, etc.

In the steam engine hot steam is admitted to the cylinder, it does work on the piston, and is discharged cooler than it entered; heat has disappeared and work has been done. It is plain that when work is done *on* a body heat is generated in it, and when work is done *by* a body some of its heat disappears. Experiment shows that when a certain amount of work has been done by a hot body a corresponding amount of heat has disappeared.

This subject has been investigated with great care, and it has been found that the ratio of the unit of heat to the unit of work is constant. That is, if 778 foot-pounds of work are done on a body, enough heat may be generated to raise the temperature of one pound of water one degree F. This equals one B. T. U.

Conversely, if a hot body—steam, for example—does work, one B. T. U. will disappear for every 778 foot-pounds of work done. This number, 778, is called the ***heat equivalent of work,*** or the ***mechanical equivalent of heat.***

## CHAPTER II.

### STEAM.

Although a body cannot become hotter unless heat passes into it or is generated in it, heat may pass into some bodies under certain conditions without raising their temperatures. The making of steam is an example of this and may be illustrated as follows: Let a vertical cylinder be fitted with a piston which is free to move up and down, but which may be loaded as much as desired. Suppose there is a certain quantity of water,—one pound for instance,—in the bottom of the cylinder and that the piston rests upon its surface. If heat be applied to the cylinder by means of a gas flame or a fire, certain results will be noticed.

First, the temperature of the water will gradually rise, until it reaches a point at which steam begins to form. Second, while steam is being formed the piston will rise, exerting a steady and constant pressure; but, although the fire continues as hot as ever, the temperature of the water and steam will remain constant. Steam formed in this way in the presence of water is called *saturated steam.* This state will continue until all of the water has been evaporated, the temperature remaining the same. Third, after the water has been evaporated, the piston will still continue to rise, but the temperature, which remained constant while steam was forming, will increase, and the steam is now said to be *superheated.*

The properties of steam with which the engineer has most to do are given in Table I., called a *steam table.*

If there had been a different load on the piston, so that the pressure on the steam and water beneath it had been different, the temperature at which steam was formed would have varied from that noted in the above case. If the pressure had been greater, the temperature would have been higher; if the water had been open to the atmosphere, steam would have formed when the water reached a temperature of 212° F. It has been shown by experiment that there is a definite relation between the temperature and the pressure exerted by saturated steam; that is, for

every pressure there is a corresponding and fixed temperature. There is no such direct relation between the temperature and pressure of superheated steam. Superheated steam at 60 pounds gauge pressure may have any temperature above 307°. At a stated pressure the temperature and volume of a given weight of superheated steam are always greater than the temperature and volume of the same weight of saturated steam.

Steam in contact with water is always *saturated.* If water is present in the form of a mist or spray, the steam is said to be *wet.* If there is no water present in this form it is called *dry.* From the results of the above experiment the following brief definitions may be given:—

*Saturated Steam* is steam of the temperature due to its pressure, not superheated.

*Superheated Steam* is steam heated to a temperature above that due to its pressure.

*Dry Steam* is steam which contains no moisture. It may be either saturated or superheated.

*Wet Steam* is steam containing moisture in the form of a mist or spray. It has the same temperature as dry saturated steam of the same pressure.

Water introduced into the presence of superheated steam will flash into a vapor until the temperature of the steam is reduced to that due to its pressure.

Water in the presence of saturated steam has the same temperature as the steam.

Should cold water be introduced, lowering the temperature of the whole mass, some of the steam would be condensed, reducing the pressure and temperature of the remainder until an equilibrium was established.

Returning to the illustration of the cylinder, it will be remembered that while steam was forming, the temperature of both the water and steam remained constant, although more heat was being supplied all of the time. This heat, which apparently disappears in the formation of steam, has been defined as *latent heat,* and when the steam is condensed it is again given out. The quantity of heat which becomes latent in changing water into

steam decreases, as the temperature at which the steam is formed, increases.

### Steam Tables.

The properties of steam with which the engineer has most to do are given in Table I., called a *steam table.*

Referring to this we find the following headings to the different columns:—

1. Pressure in pounds per square inch.
2. Temperature in degrees F.
3. Heat in the liquid above 32° F.
4. Internal latent heat.
5. External latent heat.
6. Latent heat of evaporation.
7. Total heat of evaporation.
8. Weight of a cubic foot of steam, in pounds.
9. Volume of a pound of steam, in cubic feet.
10. Ratio of volume of steam to volume of equal weight of water.

Now let us take these up briefly in order and see what each means.

1. The pressure shown by a steam gauge is 14.7 pounds less than the actual pressure inside the boiler, because the pressure of the atmosphere is acting upon the outside of the gauge, and the pointer indicates only the difference between the internal pressure and that of the atmosphere. For this reason 14.7 pounds, or in whole numbers, 15 pounds, must be added to the gauge reading to get the absolute pressure within the boiler. All comparisons in which ratios occur should be in absolute pressures. Some steam tables give the absolute pressure, while others give gauge readings.

2. As already stated, saturated steam under a given pressure always has the same temperature. The temperatures corresponding to different pressures have been accurately determined and recorded, so that by knowing the pressure one can find the corresponding temperature at once from a steam table; or, knowing the temperature, the pressure may be found in the same manner.

## TABLE I.

### THE PROPERTIES OF SATURATED STEAM.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Pressure in pounds per square inch. | Temperature in degrees F. | Heat in the liquid above 32 degrees. | Internal latent heat. | External latent heat. | Latent heat of evaporation. | Total heat of evaporation. | Weight of a cubic foot of steam in pounds. | Volume of a pound of steam in cubic feet. | Ratio of volume of steam to volume of equal weight of water. |
| ABSOLUTE PRESSURE. | | | | | | | | | |
| 1 | 102.0 | 70.0 | 981.4 | 61.6 | 1043.0 | 1113.0 | .0030 | 330.4 | 20632 |
| 2 | 126.3 | 94.3 | 962.0 | 64.1 | 1026.1 | 1120.4 | .0058 | 171.9 | 10730 |
| 3 | 141.6 | 109.7 | 950.0 | 65.6 | 1015.4 | 1125.1 | .0085 | 117.3 | 7325 |
| 4 | 153.1 | 121.3 | 940.6 | 66.8 | 1007.4 | 1128.6 | .0112 | 89.51 | 5588 |
| 5 | 162.3 | 130.5 | 933.2 | 67.6 | 1000.9 | 1131.4 | .0138 | 72.56 | 4530 |
| 6 | 170.1 | 138.4 | 927.0 | 68.4 | 995.4 | 1133.8 | .0163 | 61.14 | 3816 |
| 7 | 176.9 | 145.2 | 921.6 | 690. | 990.7 | 1135.9 | .0189 | 52.89 | 3302 |
| 8 | 182.9 | 151.2 | 916.9 | 69.6 | 986.5 | 1137.7 | .0214 | 46.65 | 2912 |
| 9 | 188.3 | 156.8 | 912.6 | 70.1 | 982.7 | 1139.4 | .0239 | 41.77 | 2607 |
| 10 | 193.3 | 161.6 | 908.7 | 70.5 | 979.2 | 1140.9 | .0264 | 37.83 | 2361 |
| 11 | 197.8 | 166.2 | 905.1 | 70.9 | 976.0 | 1142.3 | .0289 | 34.59 | 2159 |
| 12 | 202.0 | 170.4 | 901.7 | 71.3 | 973.1 | 1143.5 | .0314 | 31.87 | 1990 |
| 13 | 205.9 | 174.4 | 898.7 | 71.6 | 970.3 | 1144.7 | .0338 | 29.56 | 1845 |
| 14 | 209.6 | 178.1 | 895.8 | 72.0 | 967.7 | 1145.8 | .0362 | 27.58 | 1721 |
| GAUGE PRESSURE. | | | | | | | | | |
| 0 | 212.0 | 180.5 | 893.9 | 72.17 | 966.0 | 1146.6 | .0379 | 26.37 | 1646 |
| 1 | 216.3 | 184.9 | 890.4 | 72.55 | 963.0 | 1147.9 | .0411 | 24.33 | 1519 |
| 2 | 219.4 | 188.0 | 888.0 | 72.81 | 960.8 | 1148.8 | .0435 | 22.98 | 1434 |
| 3 | 222.4 | 191.0 | 885.6 | 73.06 | 958.7 | 1149.7 | .0459 | 21.78 | 1359 |
| 4 | 225.2 | 193.9 | 883.4 | 73.30 | 956.7 | 1150.6 | .0483 | 20.70 | 1292 |
| 5 | 227.9 | 196.6 | 881.3 | 73.52 | 954.8 | 1151.4 | .0506 | 19.73 | 1231 |
| 6 | 230.5 | 199.2 | 879.2 | 73.74 | 952.9 | 1152.2 | .0530 | 18.84 | 1176 |
| 7 | 233.0 | 201.8 | 877.2 | 73.94 | 951.2 | 1153.0 | .0554 | 18.04 | 1126 |
| 8 | 235.4 | 204.2 | 875.3 | 74.13 | 949.5 | 1153.7 | .0578 | 17.30 | 1080 |
| 9 | 237.8 | 206.6 | 873.5 | 74.32 | 947.8 | 1154.4 | .0601 | 16.62 | 1038 |
| 10 | 240.0 | 208.8 | 871.7 | 74.50 | 946.2 | 1155.1 | .0625 | 16.00 | 998.4 |
| 12 | 244.3 | 213.2 | 868.4 | 74.85 | 943.2 | 1156.4 | .0672 | 14.88 | 928.8 |
| 14 | 248.3 | 217.3 | 865.2 | 75.17 | 940.3 | 1157.6 | .0718 | 13.91 | 868.5 |
| 16 | 252.1 | 221.1 | 862.2 | 75.46 | 937.6 | 1158.8 | .0765 | 13.07 | 815.8 |
| 18 | 255.7 | 224.8 | 859.4 | 75.74 | 935.1 | 1159.9 | .0811 | 12.32 | 769.2 |
| 20 | 259.2 | 228.3 | 856.7 | 76.00 | 932.6 | 1161.0 | .0857 | 11.66 | 727.9 |
| 22 | 262.5 | 231.6 | 854.1 | 76.25 | 930.3 | 1162.0 | .0903 | 11.07 | 690.8 |
| 24 | 265.6 | 234.8 | 851.6 | 76.49 | 928.1 | 1162.9 | .0949 | 10.53 | 657.5 |
| 26 | 268.6 | 237.9 | 849.2 | 76.72 | 925.9 | 1163.8 | .0995 | 10.05 | 627.3 |
| 28 | 271.5 | 240.8 | 847.0 | 76.93 | 923.9 | 1164.7 | .1040 | 9.60 | 599.9 |
| 30 | 274.3 | 243.6 | 844.7 | 77.13 | 921.9 | 1165.6 | .1086 | 9.20 | 574.7 |
| 32 | 277.0 | 246.4 | 842.7 | 77.33 | 920.0 | 1166.4 | .1131 | 8.83 | 551.7 |
| 34 | 279.6 | 249.0 | 840.6 | 77.51 | 918.1 | 1167.2 | .1176 | 8.49 | 530.5 |
| 36 | 282.1 | 251.6 | 838.7 | 77.69 | 916.3 | 1167.9 | .1221 | 8.18 | 510.9 |
| 38 | 284.5 | 254.1 | 836.7 | 77.87 | 914.6 | 1168.7 | .1266 | 7.89 | 492.8 |
| 40 | 286.9 | 256.5 | 834.9 | 78.03 | 912.9 | 1169.4 | .1311 | 7.62 | 475.9 |
| 42 | 289.2 | 258.8 | 833.1 | 78.19 | 911.3 | 1170.1 | .1356 | 7.37 | 460.2 |
| 44 | 291.4 | 261.1 | 831.3 | 78.35 | 909.7 | 1170.8 | .1401 | 7.13 | 445.5 |
| 46 | 293.6 | 263.3 | 829.6 | 78.49 | 908.1 | 1171.5 | .1445 | 6.91 | 431.7 |
| 48 | 295.7 | 265.5 | 828.0 | 78.64 | 906.6 | 1172.1 | .1490 | 6.70 | 418.8 |
| 50 | 297.8 | 267.6 | 826.4 | 78.78 | 905.1 | 1172.7 | .1535 | 6.51 | 406.6 |
| 52 | 299.8 | 269.6 | 824.8 | 78.91 | 903.7 | 1173.3 | .1579 | 6.33 | 395.2 |
| 54 | 301.8 | 271.6 | 823.3 | 79.04 | 902.3 | 1173.9 | .1623 | 6.15 | 384.5 |
| 56 | 303.7 | 273.6 | 821.8 | 79.17 | 900.9 | 1174.5 | .1667 | 5.99 | 374.3 |
| 58 | 305.6 | 275.5 | 820.3 | 79.29 | 899.6 | 1175.1 | .1712 | 5.84 | 364.6 |
| 60 | 307.4 | 277.4 | 818.9 | 79.41 | 898.2 | 1175.7 | .1756 | 5.69 | 355.5 |
| 62 | 309.2 | 279.2 | 817.4 | 79.52 | 896.9 | 1176.2 | .1800 | 5.55 | 346.8 |
| 64 | 311.0 | 281.0 | 816.1 | 79.64 | 895.7 | 1176.7 | .1844 | 5.42 | 338.5 |

## TABLE I.

THE PROPERTIES OF SATURATED STEAM. (Continued.)

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Pressure in pounds per square inch. | Temperature in degrees F. | Heat in the liquid above 32 degrees. | Internal latent heat. | External latent heat. | Latent heat of evaporation. | Total heat of evaporation. | Weight of a cubic foot of steam in pounds. | Volume of a pound of steam in cubic feet. | Ratio of volume of steam to volume of equal weight of water. |
| GAUGE PRESSURE. | | | | | | | | | |
| 66 | 312.7 | 282.8 | 814.7 | 79.75 | 894.4 | 1177.3 | .1888 | 5.29 | 330.6 |
| 68 | 314.4 | 284.5 | 813.4 | 79.85 | 893.2 | 1177.8 | .1932 | 5.17 | 323.1 |
| 70 | 316.0 | 286.2 | 812.1 | 79.96 | 892.0 | 1178.3 | .1975 | 5.06 | 315.9 |
| 72 | 317.7 | 287.9 | 810.8 | 80.06 | 890.9 | 1178.8 | .2019 | 4.95 | 309.1 |
| 74 | 319.3 | 289.5 | 809.6 | 80.16 | 889.7 | 1179.3 | .2063 | 4.84 | 302.5 |
| 76 | 320.8 | 291.1 | 808.4 | 80.26 | 888.6 | 1179.8 | .2107 | 4.74 | 296.3 |
| 78 | 322.4 | 292.7 | 807.2 | 80.35 | 887.5 | 1180.2 | .2150 | 4.65 | 290.2 |
| 80 | 323.9 | 294.3 | 804.0 | 80.44 | 886.4 | 1180.7 | .2194 | 4.55 | 284.5 |
| 82 | 325.4 | 295.8 | 804.8 | 80.53 | 885.3 | 1181.1 | .2237 | 4.46 | 279.0 |
| 84 | 326.9 | 297.3 | 803.7 | 80.62 | 884.2 | 1181.6 | .2281 | 4.38 | 273.7 |
| 86 | 328.3 | 298.8 | 802.5 | 80.71 | 883.2 | 1182.0 | .2324 | 4.30 | 268.5 |
| 88 | 329.7 | 300.2 | 801.4 | 80.79 | 882.2 | 1182.5 | .2368 | 4.22 | 263.6 |
| 90 | 331.1 | 301.7 | 800.3 | 80.87 | 881.2 | 1182.9 | .2411 | 4.14 | 258.9 |
| 92 | 332.5 | 303.1 | 799.2 | 80.95 | 880.2 | 1183.3 | .2454 | 4.07 | 254.3 |
| 94 | 333.9 | 304.5 | 798.2 | 81.03 | 879.2 | 1183.7 | .2497 | 4.00 | 249.9 |
| 96 | 335.2 | 305.9 | 797.1 | 81.10 | 878.2 | 1184.1 | .2541 | 3.93 | 245.7 |
| 98 | 336.5 | 307.2 | 796.1 | 81.18 | 877.3 | 1184.5 | .2584 | 3.87 | 241.6 |
| 100 | 337.8 | 308.6 | 795.1 | 81.26 | 876.3 | 1184.9 | .2627 | 3.80 | 237.6 |
| 105 | 341.0 | 311.8 | 792.6 | 81.44 | 874.0 | 1185.9 | .2735 | 3.65 | 228.3 |
| 110 | 344.1 | 315.0 | 790.2 | 81.61 | 871.8 | 1186.8 | .2842 | 3.51 | 219.6 |
| 115 | 347.1 | 318.1 | 787.9 | 81.77 | 869.6 | 1187.8 | .2949 | 3.39 | 211.6 |
| 120 | 350.0 | 321.1 | 785.6 | 81.93 | 867.5 | 1188.6 | .3056 | 3.27 | 204.2 |
| 125 | 352.8 | 324.0 | 783.5 | 82.08 | 865.5 | 1189.5 | .3163 | 3.16 | 197.3 |
| 130 | 355.5 | 326.8 | 781.3 | 82.22 | 863.5 | 1190.3 | .3269 | 3.05 | 190.9 |
| 135 | 358.2 | 329.5 | 779.3 | 82.36 | 861.6 | 1191.2 | .3376 | 2.96 | 184.9 |
| 145 | 363.3 | 334.8 | 775.3 | 82.61 | 857.9 | 1192.7 | .3588 | 2.78 | 173.9 |
| 155 | 368.2 | 339.8 | 771.5 | 82.85 | 854.3 | 1194.2 | .3800 | 2.63 | 164.3 |
| 165 | 372.8 | 344.7 | 767.9 | 83.07 | 850.9 | 1195.6 | .4012 | 2.49 | 155.6 |
| 175 | 377.3 | 349.3 | 764.4 | 83.27 | 847.7 | 1197.0 | .4222 | 2.36 | 147.8 |
| 185 | 381.6 | 353.7 | 761.1 | 83.46 | 844.5 | 1198.3 | .4433 | 2.25 | 140.8 |
| 195 | 385.7 | 358.0 | 757.9 | 83.64 | 841.5 | 1199.5 | .4642 | 2.15 | 134.5 |
| 205 | 389.7 | 362.1 | 754.8 | 83.80 | 838.6 | 1200.8 | .4852 | 2.06 | 128.7 |

Columns 3, 4, and 5 may best be explained by reference to the illustration of the cylinder.

3. This shows the number of B. T. U. which have been used in raising the temperature of the water from 32° F. to that at which steam is formed, for any given pressure.

4. The internal latent heat is that which has been expended in work, in the process of evaporation, that is, in the tearing apart of the particles of water against molecular attraction.

5. The external latent heat is used in the work of expansion,

and represents the work required to raise the piston and weight in the illustration of the cylinder.

6. The latent heat of evaporation is the sum of the internal and external latent heats, and would again be given out should the steam be condensed. This is sometimes called the latent heat of steam or heat of vaporization.

7. The total heat of evaporation is the whole quantity of heat required to raise the water from 32° F. and evaporate it into steam at the given pressure, and is equal to the heat in the liquid plus the internal and external latent heat.

8. This quantity, called the *density,* shows the weight in pounds of one cubic foot of steam at the pressure taken.

9. This column gives the volume of one pound of steam at the given pressure, and is called the *specific volume.*

10. The quantities given in this column are sufficiently explained in the table, and require no further explanation.

## CHAPTER III.

### BOILER HORSE POWER.

The standard established by the committee of judges at the Centennial Exhibition in 1876 as a "boiler horse power" is the evaporation of 30 pounds of water per hour from a feed-water temperature of 100° F. into steam at 70 pounds gauge pressure. This is equivalent to the evaporation of 34.5 pounds from a temperature of 212° F. into steam at atmospheric pressure, and requires 33,305 B. T. U., which for practical purposes we may call 33,000.

The fact that an engine horse power represents work done at the rate of 33,000 foot pounds per minute often leads to more or less confusion among those not familiar with the meaning of the term horse power as applied to the two cases. A boiler of 100 H. P. may supply sufficient steam for a 200 H. P. compound condensing engine of the best make, or it may only be able to provide steam for a 50 or 75 H. P. simple non-condensing engine of old style with plain slide valve. In each case the boiler would be furnishing the same amount of steam and would be running at its normal rating of 100 H. P., but the work delivered by the engine would vary from 50 to 200 H. P., depending upon its water rate. From this it is evident that the term horse power has two different and distinct meanings when applied to engines and boilers. In the first case it means *work* done, and in the second, *pounds of steam* generated.

*Equivalent Evaporation.*—We have seen from a previous chapter that the "latent heat of evaporation" varies with the pressure, and that the "heat in the liquid" varies both with the pressure, and with the temperature of the feed water. From this it is evident that in making comparisons of the efficiency of boilers working under different conditions, we must first reduce the working conditions of each to a common standard. This standard is called the "equivalent evaporation from and at 212°," and is best explained by the following example:—

A boiler carrying a pressure of 90 pounds gauge, and supplied with feed water at a temperature of 60°, evaporates 3,000 pounds of water per hour. What is its equivalent evaporation from and at 212°?

From Table I. we find the temperature of steam at 90 pounds pressure to be 331°, and the "latent heat of evaporation" 881 B. T. U.; then for one pound of steam the "heat in the liquid" above the temperature of the feed water is $331-60=271$ B. T. U. and the "total heat" is $271+881=1{,}152$ B. T. U. Therefore, the heat required to raise the temperature of 3,000 pounds of water from 60°, and evaporate it into steam at 90 pounds pressure, is $1{,}152\times3{,}000=3{,}456{,}000$ B. T. U.

Referring again to Table I., we find the "latent heat of evaporation" for steam at atmospheric pressure to be 966 B. T. U.; therefore, $3{,}456{,}000\div966=3{,}577$ lb., which is the weight of water that would be evaporated from a temperature of 212° into steam at atmospheric pressure by the same amount of heat. The ratio $3{,}577\div3{,}000=1.19$ is called the "factor of evaporation."

Table II. gives the factors of evaporation for other conditions of feed-water temperature and steam pressure. To use the table, look in the first column for the temperature of the feed water supplied, then follow to the right until the column corresponding most nearly to the given boiler pressure is reached. The number here found will be the factor of evaporation for the case in hand, and the *actual* quantity of water evaporated, multiplied by the factor thus found will give the equivalent evaporation from and at 212°.

### Heating Surface, Grate Area, Etc.

*Heating Surface.*—The commercial horse power of a well-designed boiler is based upon its heating surface. It has been found by experience that with a properly proportioned grate area and a good chimney draft there is a definite relation between the square feet of heating surface in a boiler and the weight of water which it will evaporate in a given time.

For the best economy, a boiler for power work should be so proportioned as to have at least 1 square foot of heating surface

for each 3 pounds of water evaporated from and at 212° per hour. For the smaller sizes of heating boilers the evaporation should not exceed 2 pounds per square foot of heating surface per hour. The first figure gives $34.5 \div 3 = 11.5$ square feet of heating surface per horse power, and the second, $34.5 \div 2 = 17.2$ square feet per horse power.

## TABLE II.

### FACTORS OF EVAPORATION.

| Temp're of feed water. Degrees F. | Steam pressure by gauge. | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 | 210 | 220 |
| 32 | 1.214 | 1.216 | 1.220 | 1.222 | 1.225 | 1.227 | 1.229 | 1.231 | 1.232 | 1.234 | 1.236 | 1.237 | 1.239 | 1.240 | 1.241 | 1.243 | 1.244 | 1.245 |
| 40 | 1.206 | 1.209 | 1.212 | 1.214 | 1.216 | 1.219 | 1.220 | 1.222 | 1.224 | 1.226 | 1.227 | 1.229 | 1.230 | 1.232 | 1.233 | 1.234 | 1.236 | 1.237 |
| 50 | 1.195 | 1.197 | 1.201 | 1.204 | 1.206 | 1.208 | 1.210 | 1.212 | 1.214 | 1.215 | 1.217 | 1.218 | 1.220 | 1.221 | 1.225 | 1.224 | 1.225 | 1.226 |
| 60 | 1.185 | 1.188 | 1.191 | 1.193 | 1.196 | 1.198 | 1.200 | 1.202 | 1.203 | 1.205 | 1.207 | 1.208 | 1.210 | 1.211 | 1.212 | 1.214 | 1.215 | 1.216 |
| 70 | 1.175 | 1.178 | 1.180 | 1.183 | 1.185 | 1.187 | 1.189 | 1.191 | 1.193 | 1.194 | 1.196 | 1.19, | 1.199 | 1.200 | 1.202 | 1.203 | 1.205 | 1.206 |
| 80 | 1.164 | 1.167 | 1.170 | 1.173 | 1.175 | 1.177 | 1.179 | 1.181 | 1.183 | 1.184 | 1.186 | 1.187 | 1.189 | 1.190 | 1.192 | 1.193 | 1.194 | 1.195 |
| 90 | 1.154 | 1.157 | 1.160 | 1.162 | 1.165 | 1.167 | 1.169 | 1.170 | 1.172 | 1.174 | 1.176 | 1.177 | 1.179 | 1.180 | 1.181 | 1.183 | 1.184 | 1.185 |
| 100 | 1.144 | 1.147 | 1.150 | 1.152 | 1.154 | 1.156 | 1.158 | 1.160 | 1.162 | 1.164 | 1.165 | 1.167 | 1.168 | 1.170 | 1.171 | 1.172 | 1.174 | 1.175 |
| 110 | 1.133 | 1.136 | 1.139 | 1.142 | 1.144 | 1.146 | 1.148 | 1.150 | 1.152 | 1.153 | 1.155 | 1.156 | 1.158 | 1.159 | 1.160 | 1.162 | 1.163 | 1.164 |
| 120 | 1.123 | 1.126 | 1.129 | 1.131 | 1.133 | 1.136 | 1.138 | 1.140 | 1.141 | 1.143 | 1.145 | 1.146 | 1.147 | 1.149 | 1.150 | 1.151 | 1.153 | 1.154 |
| 130 | 1.113 | 1.116 | 1.118 | 1.121 | 1.123 | 1.125 | 1.127 | 1.129 | 1.130 | 1.132 | 1.134 | 1.136 | 1.137 | 1.138 | 1.140 | 1.141 | 1.142 | 1.144 |
| 140 | 1.102 | 1.105 | 1.108 | 1.110 | 1.113 | 1.115 | 1.117 | 1.119 | 1.120 | 1.122 | 1.124 | 1.125 | 1.127 | 1.128 | 1.129 | 1.131 | 1.132 | 1.133 |
| 150 | 1.091 | 1.095 | 1.098 | 1.100 | 1.102 | 1.104 | 1.106 | 1.108 | 1.110 | 1.111 | 1.113 | 1.115 | 1.116 | 1.118 | 1.119 | 1.120 | 1.121 | 1.123 |
| 160 | 1.081 | 1.084 | 1.087 | 1.090 | 1.092 | 1.094 | 1.096 | 1.098 | 1.100 | 1.101 | 1.103 | 1.104 | 1.106 | 1.107 | 1.108 | 1.110 | 1.111 | 1.112 |
| 170 | 1.070 | 1.074 | 1.077 | 1.079 | 1.081 | 1.083 | 1.085 | 1.087 | 1.089 | 1.091 | 1.092 | 1.094 | 1.095 | 1.097 | 1.098 | 1.099 | 1.101 | 1.102 |
| 180 | 1.060 | 1.063 | 1.066 | 1.069 | 1.071 | 1.073 | 1.075 | 1.077 | 1.079 | 1.080 | 1.082 | 1.083 | 1.085 | 1.086 | 1.088 | 1.089 | 1.090 | 1.091 |
| 190 | 1.050 | 1.053 | 1.056 | 1.058 | 1.060 | 1.063 | 1.065 | 1.066 | 1.068 | 1.070 | 1.071 | 1.073 | 1.074 | 1.076 | 1.077 | 1.078 | 1.080 | 1.081 |
| 200 | 1.039 | 1.043 | 1.045 | 1.048 | 1.050 | 1.052 | 1.054 | 1.056 | 1.058 | 1.059 | 1.061 | 1.063 | 1.064 | 1.065 | 1.067 | 1.068 | 1.069 | 1.071 |
| 210 | 1.029 | 1.032 | 1.035 | 1.037 | 1.040 | 1.042 | 1.044 | 1.046 | 1.047 | 1.049 | 1.051 | 1.052 | 1.053 | 1.055 | 1.056 | 1.057 | 1.059 | 1.060 |

It is customary for most builders of tubular boilers to rate them on a basis of 12 square feet of heating surface per horse power. This is a safe figure provided the heating surfaces are kept free from soot and ashes, and are so arranged as to produce an even flow of the hot gases over them. The interior of the boiler must also be kept free from sediment and incrustation if the best results are to be obtained. As it is practically impossible to run a boiler under these favorable conditions at all times, especially in heating plants of small or medium size, it seems best to make a slight allowance by providing 15 square feet of heating surface per horse power, which has been found safe and to give good results in practice. This also allows a margin for forcing in

case of an emergency. With clean tubes and careful firing, a boiler having these proportions may be made to develop a capacity at least 30 per cent above its nominal rating.

All computations and tables relating to tubular boilers which occur in the following pages are based on 15 square feet of heating surface per horse power.

Authorities differ in regard to the proper method of computing the heating surfaces of tubular boilers. In general, all surface is taken which is exposed to the hot gases on one side and to the water on the other. There is some question as to whether the front head should be considered as effective surface because the gases in passing from the tubes to the uptake flow away from it instead of against it as they do in the case of the rear head. A safe rule, and one by which tables appearing in a later chapter are computed, is to take one half the area of the shell, two thirds of the rear head, less the tube area, and the interior surface of all the tubes.

In the case of water-tube boilers of the best makes, it is customary to allow 10 square feet of heating surface per horse power. This is due to the greater proportion of heating surface exposed directly to the fire, better circulation of water within the boiler, and, as they are largely used for power purposes, they usually receive better care.

*Rate of Combustion.*—The coal burned per square foot of grate surface per hour in power plants with natural draft will average from 12 to 15 pounds for anthracite, and from 15 to 18 pounds for bituminous. When forced draft is employed, a combustion of 20 to 30 pounds is often obtained with stationary boilers, while a much higher rate is common in locomotive practice. In the case of heating boilers of good size, from 8 to 10 pounds is a fair average; this, however, is often much less in poorly cared for boilers of small size. House heating boilers of the cast-iron sectional type usually burn about 5 pounds of coal per square foot of grate per hour when properly cared for. It is evident that no fixed rule can be given for determining the rate of combustion in any given case, as it depends so largely upon the chimney draft and grade of fuel used.

*Rate of Evaporation.*—This, in well-proportioned boilers with clean tubes, varies from 8 to 10 pounds of steam per pound of coal; the latter representing more nearly the performance of the best makes of water-tube boilers. In the case of small heating boilers below 20 H. P., the evaporation is more commonly from 6 to 7 pounds per pound of coal. This, like the rate of combustion, is a variable factor, depending upon the character and arrangement of the heating surfaces and upon the proper proportioning of the grate area.

*Grate Area.*—The required amount of grate area per horse power and the proper ratio of heating surface to grate area vary a good deal, depending upon the character of the fuel and the chimney draft.

By assuming the probable rates of combustion and evaporation, we may compute the required grate area for any boiler by the equation

$$S = \frac{\text{H. P.} \times 34.5}{E \times C}$$

in which

$S$ = total grate area, in square feet.
$E$ = pounds of water evaporated per pound of coal.
$C$ = pounds of coal burned per square foot of grate per hour.

TABLE III.

GRATE AREA PER HORSE POWER.

| Pounds of steam per pound of coal. | Pounds of coal burned per square foot of grate per hour. | | | | |
|---|---|---|---|---|---|
| | 8 | 10 | 12 | 15 | 20 |
| 10..... | .43 | .35 | .28 | .23 | .17 |
| 9..... | .48 | .38 | .32 | .25 | .19 |
| 8..... | .54 | .43 | .36 | .29 | .22 |
| 7..... | .62 | .49 | .41 | .33 | .24 |
| 6..... | .72 | .58 | .48 | .38 | .29 |

Table III. gives the approximate grate area per horse power for different rates of evaporation and combustion as computed by the above formula.

With an evaporation of 10 pounds of steam per pound of coal,

and a combustion of 15 pounds of coal per square foot of grate per hour, which may be taken as the average performance in a first class plant, with water-tube boilers, 0.23 square foot of grate surface would be required per horse power. For a heating plant with tubular boilers, and rates of evaporation and combustion of 8 and 10, respectively, 0.43 square foot of grate surface per horse power would be required.

The difference in efficiency between the boilers in a power plant and those in a heating plant does not depend in any way upon the use made of the steam, but upon the larger size of the boilers, the greater care bestowed upon them, and the employment of more experienced firemen.

*Ratio of Heating to Grate Surface.*—This in tubular boilers for heating usually varies from 30 to 40 under ordinary conditions. Taking the lower figure and assuming 15 square feet of heating surface per horse power, a grate area of 0.5 square foot per horse power is called for, while with the higher figure an area of 0.38 square foot is required. In the case of water-tube and power boilers the ratio is usually somewhat greater, running from 40 to 50 or more.

Taking these figures and assuming 10 square feet of heating surface per horse power, we find the required grate areas to be 0.25 and 0.20 square foot, respectively, all of which correspond very closely with the figures given in Table III. for the corresponding types of boilers. The most efficient ratio in any given case will depend upon the grade of coal to be used, the rate of combustion, and the character and arrangement of the heating surfaces. In any given boiler there is a limit to the quantity of heat which it can absorb economically, so that, if the rate of combustion is increased, the grate area must be correspondingly diminished, else the gases will pass to the chimney at a high temperature and heat will thus be wasted.

Bituminous coal requires a higher ratio between heating and grate surfaces, because the soot deposited upon the tubes reduces their efficiency, and also because the rate of combustion is usually somewhat greater than with anthracite.

Mr. Geo. H. Barrus in his book, "Boiler Tests," states that in a series of three tests on tubular boilers using anthracite coal, he

found no gain in efficiency by increasing the ratio over 36 when the rate of combustion was not over 12 pounds of coal per square foot of grate per hour. With bituminous coal he recommends a ratio of 45 or 50 when the rate of combustion is over 10 or 12 pounds of coal per hour.

The ratio of heating to grate surface in sectional cast iron boilers for house heating, ranges from 15 to 25 in the best makes. This low ratio is due to the slow rate of combustion commonly employed.

*Coal per Horse Power.*—It has been found by experience that a combustion of about 0.3 pound of coal per hour for each square foot of heating surface seems to give the most satisfactory results. This gives an average coal consumption of $15 \times 0.3 = 4.5$ pounds per horse power per hour for tubular boilers and $10 \times 0.3 = 3.3$ pounds for water-tube boilers. These figures will vary somewhat with the quality of the coal, but will be found useful in making approximations for average boiler practice.

### Computing Boiler Horse Power.

Buildings of large size require steam for one or more of the following purposes: Heating; ventilation; lighting; hot water; and power for refrigeration and elevator service.

The boiler power required for these different uses will be taken up more in detail in the following chapters, but for convenience in making approximations for the more important items a few brief rules will be given here.

*Boiler Power for Heating.*—The boiler power required for heating may be computed in several different ways. In the case of new buildings it is customary to compute the total heat loss from the building in B. T. U. in the coldest weather, by one of the rules given in Part III., Chapter III., and divide the results by 33,000. This gives the boiler horse power necessary to evaporate the required amount of steam from and at 212°, but the conditions of temperature and pressure are so similar to this in low-pressure heating that no correction is necessary.

Sometimes it is desired to install a boiler plant in a building where the radiation is already in place. In this case we may use

the following relations between radiating surface and boiler power, assuming that one boiler horse power will supply

130 square feet of direct cast-iron radiation.
100 square feet of direct wrought iron pipe coils.
50 square feet of indirect cast iron radiation.
20 square feet of steam blast coils.

The boiler power computed in this manner should be increased about 10 per cent to cover the loss by radiation from the steam mains and returns.

*Power of Cast Iron Sectional Boilers.*—Cast iron sectional, and other heating boilers of similar design, are usually rated by the square feet of direct radiation which they will supply instead of by horse power. The published ratings are usually somewhat in excess of the *economical* capacities of the boilers, and it is better to compute the size required in any given case rather than to rely upon the catalogue rating.

For the best types we may assume an average combustion of 5 pounds of coal per square foot of grate per hour, and an average efficiency of 60 per cent, which corresponds to about 8,000 B. T. U. per pound of coal available for useful work.

The most efficient rate of combustion, however, will depend to some extent upon the ratio between the heating and grate surfaces. A combustion of about one fourth pound of coal per hour for each square foot of heating surface seems to give the best results for boilers of this type, so that by knowing the ratio of heating surface to grate area we may easily compute the most efficient rate of combustion for any given make and size of boiler, and from this determine the necessary grate area.

*Example.*—The heat loss from a building is 480,000 B. T. U. per hour and we wish to use a sectional boiler in which the ratio of heating surface to grate area is 24. What will be the most efficient rate of combustion, and the required grate area?

Solving, $480{,}000 \div 8{,}000 = 60$ lb. of coal required per hour, and $24 \div 4 = 6$, the most economical rate of combustion to employ. Therefore, the required grate area is $60 \div 6 = 10$ sq. ft. This will be taken up more in detail under Direct Steam Heating.

*Boiler Power for Ventilation.*—The heat, in thermal units, required to raise any given volume of air through any number of degrees in temperature is equal to

$$\frac{\text{Volume of air in cubic feet} \times \text{Degrees raised}}{55}$$

Knowing the cubic feet of air to be delivered per hour to a building, and the number of degrees its temperature is to be raised, we can easily compute the B. T. U. required, and this divided by 33,000 will give the boiler horse power, as before.

*Example.*—The heat loss from a building is 1,650,000 B. T. U. per hour. The air supply for ventilation is to be 1,500,000 cubic feet per hour, raised through 70°. What will be the total boiler horse power required?

$$\text{H. P. for heating} = \frac{1{,}650{,}000}{33{,}000} = 50$$

$$\text{H. P. for ventilation} = \frac{1{,}500{,}000 \times 70}{55 \times 33{,}000} = 58$$

$$\text{Total} \qquad 108$$

*Boiler Power for Supplying Steam Engines.*—Computations for power boilers are based on the steam consumption of the engines. This varies a good deal, even with the same type of engine, depending upon the size and speed, the pressure carried, and the point of cut-off.

Table IV. on the next page gives about the average steam consumption per indicated horse power per hour for first class engines of medium size.

The higher figures may be used for engines from 75 to 200 H. P. and the lower for sizes from 200 to 500 H. P. For engines smaller than 75 H. P. they should be increased slightly. The last item is for compound engines of larger sizes, such as are met with in manufacturing plants.

Having determined the probable weight of steam required per hour for the particular type of engine to be used, and knowing the temperature of the feed water, and the boiler pressure to be carried, the weight of steam can be reduced to an equivalent evapora-

tion from and at 212°, and this result divided by 34.5 will give the boiler horse power required.

TABLE IV.

AVERAGE STEAM CONSUMPTION OF ENGINES.

| Type of engine | Pounds of steam per indicated horse power per hour | |
|---|---|---|
| | Non-condensing | Condensing |
| Simple high speed | 30 to 34 | 22 to 26 |
| Simple medium speed | 28 " 32 | 21 " 25 |
| Simple Corliss | 26 " 30 | 20 " 24 |
| Compound high speed | 24 " 28 | 18 " 22 |
| Compound medium speed | 23 " 27 | 17 " 21 |
| Compound Corliss | 22 " 26 | 16 " 20 |
| Compound Corliss of over 500 horse power | 20 " 24 | 14 " 18 |

*Example.*—What horse power of boiler will be required to supply steam at 100 pounds gauge pressure from feed water at 60° temperature, for a compound-condensing Corliss engine of 200 indicated horse power?

Taking the higher water rate for this type of engine from Table IV., we have $200 \times 20 = 4{,}000$ pounds of steam required per hour. Looking in Table II., we find the factor of evaporation for the conditions given to be 1.19. Therefore, $4{,}000 \times 1.19 = 4{,}760$, which is the equivalent evaporation from and at 212°, and $4{,}760 \div 34.5 = 138$, the boiler horse power required.

If steam is to be used for other purposes, such as the running of feed pumps, etc., the power must be increased accordingly. It is also well to allow a margin for a future increase in the power of the engine, should occasion require it. In computing the power of a boiler in this manner it is well to increase the result from 10 to 20 per cent as a reserve for the reasons given above.

*Boiler Power for Pumps.*—The boiler power required for running a pump is computed in a similar manner to that already described for an engine. The rating or capacity of a pump, however, is usually expressed in gallons of water per minute raised to a given height, instead of in horse power as in the case of an engine.

The weight of water, in pounds per minute, multiplied by the height in feet, to which it is raised, divided by 33,000, will give the useful or delivered work of the pump expressed in horse power.

The friction of the moving parts of a pump, and of the water flowing through the passages and valves, is so great that under ordinary working conditions not much more than 50 per cent of the indicated horse power of the steam cylinders is utilized in doing useful work. This, together with the fact that steam is not used expansively, calls for a large amount of steam in proportion to the work done as shown by Table V., which gives the average steam consumption of the ordinary duplex pump.

TABLE V.

AVERAGE STEAM CONSUMPTION OF DUPLEX PUMPS.

| Type of pump. | Pounds of steam per hour per delivered horse power. |
|---|---|
| Simple non-condensing..... | 120 |
| Compound non-condensing..... | 65 |
| Triple non-condensing..... | 40 |
| High duty non-condensing..... | 30 |

In measuring the head against which a pump is working, take the vertical distance between the surface of the water in the suction reservoir and the highest point in the discharge pipe. If the pump is delivering against a pressure, as in feeding a boiler, reduce the pressure to "feet head," by dividing the pressure per square inch by 0.4.

*Examples.*—A pump is discharging 4,000 pounds of water per minute into a tank 50 feet above it. The surface of the water in the reservoir from which it is taken is 10 feet below the pump. What is the useful work done by the pump?

Solving, $50 + 10 = 60$ ft. = the total head against which the pump is working, and

$$\frac{4{,}000 \times 60}{33{,}000} = 7.2 \text{ H. P.}$$

A boiler feed pump is delivering 200 pounds of water per minute against a pressure of 150 pounds. The water is taken from a reservoir 5 feet below the pump. What boiler horse

power will be required, assuming the pump to use 120 pounds of steam per hour per delivered horse power?

Here $150 \div 0.4 = 375$ ft. head and $375 + 5 = 380$ ft. total head; then,

$$\frac{200 \times 380}{33{,}000} = 2.3 \text{ H. P.}$$

from which the steam required will be $2.3 \times 120 = 276$ lb. per hour.

If the temperature of the feed water is 60°, and the boiler pressure 150 pounds, the factor of evaporation from Table II. will be 1.2, and $276 \times 1.2 = 331$ lb., the equivalent evaporation from and at 212°. Therefore, $331 \div 34.5 = 9.6$, the boiler horse power required.

In the above examples it has been assumed that the horizontal runs in the suction and discharge pipes are short and no account has been taken of frictional resistance.

*Boiler Power for Electric Lighting.*—The power required for electric lighting can be determined approximately by assuming that one horse power of electrical energy will supply the number of lamps of different types as given in Table VI.

TABLE VI.

NUMBER AND TYPE OF LAMPS SUPPLIED BY ONE HORSE POWER.

| No. of lamps supplied by one horse power. | Type and power of lamp. |
|---|---|
| 12 | 16 candle-power incandescent. |
| 6 | 32 candle-power incandescent. |
| 2.2 | half arc, open. |
| 1.5 | full arc, open. |
| 1 to 1.5 | closed arc. |

The efficiency of a first-class generating set (engine and dynamo) including the losses in transmission may be taken as about 75 per cent, when located in or near the building to be lighted, so that the electric horse power necessary to supply the lamps, divided by 0.75, will give the indicated horse power of the engine. From this the boiler horse power can be determined as already described.

*Example.*—What boiler horse power will be required to furnish steam for a lighting plant carrying 2,400 incandescent lamps

of 16 candle power and 600 of 32 candle power and 40 closed arcs of the larger size? The boiler pressure is to be 100 pounds, and the feed water is to be delivered at an average temperature of 70°. The engines are to be high-speed, compound, non-condensing, using 28 pounds of steam per indicated horse power.

From the above we have,

$$\begin{aligned} 2{,}400 \div 12 &= 200 \\ 600 \div 6 &= 100 \\ 40 \div 1 &= 40 \\ & \text{—} \\ & 340 \end{aligned}$$

This is the horse power of electrical energy required of the dynamos, and $340 \div 0.75 = 453$, I. H. P. of engines, whence, $453 \times 28 = 12{,}684$ pounds of steam required per hour. The factor of evaporation for 100 pounds steam pressure and 70° temperature of feed water is 1.15; $12{,}684 \times 1.15 = 14{,}586$ pounds, the equivalent evaporation from and at 212°, and

$$14{,}586 \div 34.5 = 422,$$

the boiler horse power required.

*Boiler Power for Hot Water Heating.*—This is easily computed if the quantity of water and its initial and final temperatures are known.

*Example.*—What boiler horse power will be required to raise the temperature of 500 gallons of water per hour from 50° to 180°?

$500 \times 8.3 = 4{,}150$ lb. and $180° - 50° = 130°$ rise in temperature, from which it is evident that $4{,}150 \times 130 = 539{,}500$ B. T. U. are required. This calls for $539{,}500 \div 33{,}000 = 16.3$ boiler H. P.

Placing this in the form of an equation we have,

$$\text{H. P.} = \frac{G \times 8.3 \times (T_2 - T_1)}{33{,}000}$$

in which

$G$ = gallons of water to be heated per hour.
$T_1$ = initial temperature.
$T_2$ = final temperature.

### Calculating Power for Refrigeration.

*The Refrigeration Process.*—Mechanical refrigeration is commonly produced by liquifying a gas like ammonia or sulphur-dioxide under a high pressure, and then allowing it to vaporize at a lower pressure.

The process of vaporization absorbs heat the same as when steam is formed in a boiler, and this results in lowering the temperature of the medium surrounding the pipe or chamber in which vaporization takes place.

In the ammonia *compression* machine the gas is first compressed, then passed through cooling coils called the condenser, where it is liquified. From here it is slowly fed into a coil submerged in brine, one end of which is connected with the suction of the compressor. As the small stream of liquid ammonia flows into the coil, which is under a lower pressure, it at once vaporizes, and in so doing absorbs a certain amount of heat from the surrounding brine, thus lowering its temperature. The brine is then circulated through coils arranged along the ceilings and walls of the rooms to be cooled. Sometimes the coils in which vaporization occurs are made to take the place of the brine coils, and the heat is abstracted directly from the air of the room without the use of brine.

In the *absorption* machine, so called, the results are obtained in a somewhat different manner, although the general principles involved are the same.

The capacity of a refrigerating plant is usually expressed in tons of refrigeration or "ice-melting effect." For example, a 10-ton machine will produce the same cooling effect in 24 hours as the melting of 10 tons of ice, or, in other words, will extract the same amount of heat from the brine as would be required to melt 10 tons of ice into water at a temperature of 32 degrees.

*Boiler Power for Refrigeration.*—The indicated horse power required per ton of refrigeration depends upon the suction and condenser pressures, which in turn are governed by the temperature and amount of the condensing water used. Under ordinary conditions where condensing water must be obtained at average city prices, the most economical results are obtained with suction

pressures ranging from 20 to 30 pounds, and condenser pressures of 140 to 150 pounds gauge.

Under these conditions, 1 indicated horse power at the steam cylinder will produce about 60 pounds of ice-melting effect per hour, or 0.75 ton per 24 hours. This will, of course, vary somewhat with the range of pressure and also with the size and type of machine, but in the absence of more exact data, may be used for approximate results. Another method in common use is to provide 1.5 indicated horse power per ton of refrigeration, which is slightly more than in the previous case. Knowing the indicated horse power of the compressor, the probable steam consumption can be determined from Table IV., and the boiler power computed the same as for a steam engine of the same type and capacity.

If the machine is motor driven, the required power must be increased from 20 to 25 per cent for losses in the generator and motor.

*Example.*—What boiler horse power will be required to operate a 50-ton refrigerating plant running 24 hours per day; the compressor being of the steam driven type, with a simple non-condensing engine using 32 pounds of steam per indicated horse power per hour? Temperature of feed water 60 degrees, boiler pressure 80 pounds.

I. H. P. of compressor $= 50 \div 0.75 = 66.6$. Calling it 70, the steam consumption will be $70 \times 32 = 2{,}240$ pounds per hour. The factor of evaporation for the conditions stated is 1.19, from which the boiler horse power is found to be

$$\frac{2{,}240 \times 1.19}{34.5} = 77$$

If the machine were motor driven the indicated horse power of the engine operating the generator would be $70 \times 1.2 = 84$, and the steam consumption would be figured accordingly.

*Power for Ice Making.*—If power is required for the actual manufacture of ice, instead of the cooling of brine or other medium, the boiler power as above computed should be doubled. This is made necessary on account of the introduction of other heat losses not present in the simple process of cooling.

### Calculating Power for Elevators.

*Power for Operating Elevators.*—The power necessary to operate an elevator depends upon its size, the method of construction and counterbalancing, the speed, and the efficiency. Placing these conditions in the form of an equation, we have,

$$\text{H. P.} = \frac{(W + w) \times S}{E \times 33{,}000}$$

in which

$W$ = weight of *live load.*
$w$ = unbalanced weight of car.
$S$ = speed in feet per minute.
$E$ = efficiency.

In addition to the above, a certain amount of power is required for accelerating the car each time it is started on its upward trip. This, however, is relatively small when compared with the total work done and has been cared for in an approximation as noted below.

The elevators in most common use for passenger service are of the hydraulic and electric types, while for freight work steam and belted elevators may be added; the latter being connected directly with the line shaft in shops and factories.

The general method of computing the power is the same for both hydraulic and electric elevators; but as they differ in detail, it is advisable to take them up separately.

The live load for a passenger elevator is usually figured on a basis of 60 to 80 pounds per square foot of floor space, and the weight of the elevator itself from 100 to 125 pounds per square foot, which also includes the safety device. These figures will be found ample for cars of ordinary construction, but may be exceeded somewhat in the case of metal cars of especially massive design.

*Boiler Power for Hydraulic Elevators.*—It is common practice with elevators of this type to counterbalance them up to about three fourths of the weight of the car. The speed varies from about 200 to 600 feet per minute, 400 being about the average

for office buildings of medium size. The efficiency is about 60 per cent.

In computing the boiler power, it must be taken into consideration that all of the elevators will probably not be running at one time at their maximum capacity, and also that power is required only on the upward trip, as the weight of the car causes it to descend under the control of a suitable braking device.

When there is no definite information at hand, it is customary to compute the power necessary to run all of the elevators at one time under full load, and base the boiler power on 0.7 of this result, which also includes the power required for accelerating the car.

*Example.*—An office building has three hydraulic elevators, each having a floor space of 30 square feet. What boiler power should be provided, using the average data given below?

Live load, 70 pounds per sq. ft. of floor space; weight of elevator, 100 pounds per sq. ft. of floor space; speed, 400 feet per minute; efficiency, 60 per cent; steam consumption of pumps, 65 pounds per H. P. per hour.

From the above we have,

$$W = 30 \times 70 \times 3 = 6{,}300$$
$$w = 30 \times 100 \times 3 \times 0.25 = 2{,}250.$$

Then, for a continuous upward movement with a full load the required horse power would be

$$\frac{(6{,}300 + 2{,}250) \times 400}{0.60 \times 33{,}000} = 172$$

Now, of course, under actual conditions one half of the time is devoted to the downward trips, and the power required is therefore only one half of the above, or 86 H. P. Making allowance for stops at the various floors and for the time that part of the elevators are idle, we may assume that it will be sufficient to provide for 70 per cent of the above, or $0.70 \times 86 = 60$ H. P. The steam consumption under the conditions stated would be $60 \times 65 = 3{,}900$ pounds per hour.

Assuming 30 pounds of steam per boiler horse power, which may be taken with sufficient accuracy when the pressure and

feed water temperature are not given, we have for the required boiler horse power, $3{,}900 \div 30 = 130$.

For the type of pumps ordinarily used for elevator work the steam consumption given in Table V. may be used with approximate results.

*Types of Electric Elevators.*—The most common types of electric elevators are the *drum, screw,* and *duplex.* The speeds at which these are commonly run may be taken as 350, 500, and 600 feet per minute, respectively, although for regular work, speeds above 400 feet are not usually found desirable for the average building.

So far as the necessary power is concerned, the drum and duplex types may be considered together. The efficiency of these machines commonly runs from 50 to 70 per cent, although, theoretically, the former is the more efficient type. In practice it is not customary to count on much more than 50 per cent, which gives results on the side of safety.

The method of balancing these elevators differs from the hydraulic, in that the entire weight of the car and from 40 to 50 per cent of the maximum live load is counterbalanced. From this it is evident that with no load the power required to pull the car down is that necessary to raise the counterweight, which is equal to one half the maximum live load, and to overcome the friction of the machine. When the car is half full, it is balanced, and the power required is that due to friction only. At full load the conditions are the same as for an empty car, except the power is required during the upward trip instead of the downward.

*Power for Operating Electric Elevators.*—From the above it is evident that power may be required for both the upward and downward trips, depending upon the number of people in the car, but it will never be as great at any one time as in the case of the hydraulic elevator.

*Example.*—Taking the same conditions as in the preceding example, what boiler power will be required to operate electric elevators of the drum type, having an efficiency of 50 per cent and a speed of 300 feet per minute?

In this case $w$, the unbalanced weight of the car, disappears, and the maximum live load is equal to only one half the weight of

the people in the car, the other half being counterbalanced, so that $W = 30 \times 70 \times 3 \times 0.5 = 3{,}150$ pounds, from which

$$\text{H. P.} = \frac{3{,}150 \times 300}{0.50 \times 33{,}000} = 57$$

If the full load were carried on both upward and downward trips, or sufficient of it on the downward trip to overbalance the counterweight and the friction of the car, the conditions would be the same as in the case of the hydraulic elevator; that is, power would only be required on the upward trip. This condition, however, does not hold, especially in the case of office buildings, where during the morning hours the maximum loads are on the upward trips with empty, or nearly empty, cars coming down. Under these conditions the power is practically the same on both trips, owing to the necessity of raising the counterweight when the car is descending. This makes it necessary to treat the problem the same as though the machine were raising a continuous load.

Assuming as before that a certain amount of time is required for passengers to enter and leave the car, and that all of the cars will not be running at one time, we may take 70 per cent of the above or $57 \times 0.7 = 40$ as the maximum horse power to be delivered continuously by the motor.

*Boiler Power for Electric Elevators.*—Assuming efficiencies of 80, 90 and 85 per cent for the motor, generator and engine, respectively, the required indicated horse power of the engine will be

$$\frac{40}{0.80 \times 0.90 \times 0.85} = 62$$

The boiler power will of course depend upon the water rate of the engine. Assuming that a simple non-condensing engine is employed, requiring 30 pounds of steam per indicated horse power per hour, the boiler power will be practically the same as that of the engine, that is, 62 H. P.

The power required to operate duplex elevators is practically the same except where a higher speed may be allowed.

The method of balancing a screw machine is practically the

same as for the hydraulic type. The efficiency of this machine may be taken as about 70 per cent.

The horse power for driving elevators of this type is calculated the same as for the hydraulic, except for the higher efficiency. After the power of the motor has been computed, the boiler power may be determined as in the preceding example.

Freight elevators are computed in the same way, except they are run at lower speeds, and are built especially to carry the desired load in each particular case. When applying these methods of computation, the engineer should obtain all the data possible regarding the type of machine to be used, the probable speed, efficiency, etc., before proceeding in any particular case; but if any of these data are lacking, the average figures already given may be used with approximate results.

### General Considerations.

*Total Boiler Power.*—When a building contains a power plant, the exhaust steam not used for feed-water heating is commonly turned into the heating system. In this case the boiler power for supplying the engines and pumps is first computed, and about 65 per cent of the steam furnished for this purpose may be considered as available in the exhaust for heating purposes. If this amount is less than is required for heating, in the coldest weather, additional boiler power must be provided to make up the deficiency.

*Number of Units.*—In designing a plant of any considerable size it is better to use two or more smaller boilers rather than a single large one, and it is also well to provide for a certain amount of reserve power for use in case of a breakdown or when it is desired to shut down a boiler for cleaning or inspection. In a heating plant, if sufficient power is provided for the coldest weather, there will be much of the time when only a part of the boilers will be in use, but in the case of a power plant where the demand for steam is practically constant, one or more extra boilers, depending upon the size of the plant, should be kept in reserve.

## CHAPTER IV.

### TYPES OF BOILERS.

Steam boilers are divided into two general classes, known as externally fired and internally fired boilers. These, owing to the course taken by the gases, are again divided into shell or fire-tube boilers, and water-tube boilers.

In the former the heat is applied to the interior of the tubes and in the latter to the exterior.

Externally fired boilers are more commonly used in this country for power and heating, while internally fired boilers are extensively used in marine practice.

There is a great variety of boilers upon the market, but space can only be taken for a few representative types.

*Relative Merits.*—No particular rule can be laid down for the selection of a boiler. The style adopted must depend largely upon the taste of the purchaser, the maximum price to be paid, the available space, the pressure to be carried, the quality of the feed-water and other conditions under which the boiler is to operate. Experience has shown that when boilers of any of the well-known types are equally well designed and proportioned for the work to be done, and are operated with the same skill, and provided with the same quality of fuel, one type will give about the same economy as another.

The advantages of the fire tube boiler are: first, a greater water capacity, which gives a less rapid fluctuation of the water-line and thus requires less careful attention; second, lower cost of installation; and third, less height than some types of water-tube boilers, which is often of much importance in low basements.

The water-tube boiler has the advantage of greater safety. as the water is divided into small masses, which prevents serious results in the case of rupture. The large amount of heating surface next to the fire increases the transmission of heat and prevents over-heating. The draft area, which is limited in fire-tube boilers, is increased in this type of boiler, thus giving a slower

movement to the gases and a greater opportunity for their heat to be absorbed before entering the chimney.

Another advantage is that riveted joints are removed from the fire. Also, as the steam enters one end of the drum and leaves it at the other the water and steam are more thoroughly separated, and the circulation of water being rapid and in one direction, gives less opportunity for sediment to be deposited on the heating surfaces than in the case of fire-tube boilers. Steam may be raised rapidly, as the water is divided into small streams which pass through the hottest portions of the fire. The loss of heat from the accumulation of ashes and soot is less than in the case of fire-tube boilers, as they do not adhere so readily to the outside of the tubes as to the inside.

### Fire-tube Boilers.

*Horizontal Tubular Boiler.*—This boiler consists of a cylindrical shell of wrought iron or steel with fire tubes terminating in

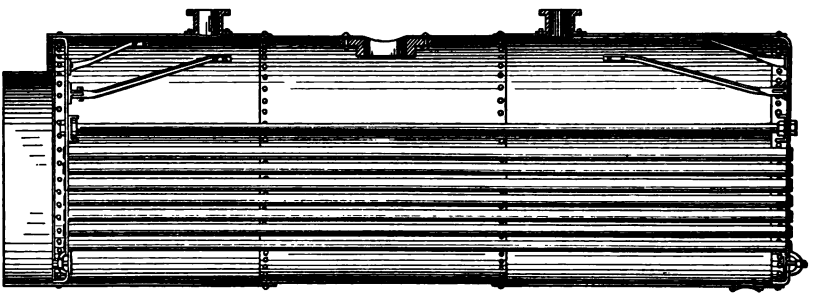


Fig. 1. Horizontal Tubular Boiler.

the two flat ends. The tubes are usually from two and one half inches to four inches in diameter, depending upon the length of the shell. The steam space occupies about one third of the volume of the boiler and the remainder is filled with water; the water line should be from four to six inches above the tops of the tubes. The heads below the water line are supported by the tubes, and the remaining portions are stayed by through braces or diagonal stays. Fig. 1 shows a longitudinal section through a boiler of this kind. Horizontal tubular boilers require a brick setting,

# TABLE VII.

## DIMENSIONS OF TUBULAR BOILERS.

| Diameter of boiler | Number of tubes | Diameter of tubes | Area through tubes in square feet | Square feet heating surface in heads | Square feet heating surface in one linear foot shell and tubes | Horse power in one linear foot shell and tubes | Length of tubes | Horse power | Rate of evaporation 9 lb. steam per lb. of coal | | | | Rate of evaporation 8 lb. steam per lb. of coal | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Size of grate | Size of uptake | Area smoke-pipe, sq. inches | Coal per sq. foot of grate per hour | Size of grate | Size of uptake | Area smoke-pipe, sq. inches | Coal per sq. foot of grate per hour |
| 30 | 28 | 2½ | 0.78 | 2.8 | 20.7 | 1.37 | 6 | 8.5 | ..... | ..... | .... | ..... | 24 by 36 | 10 by 14 | 140 | 6 |
| | | | | | | | 7 | 9.9 | ..... | ..... | .... | ..... | 24 " 36 | 10 " 14 | 140 | 7 |
| | | | | | | | 8 | 11.2 | ..... | ..... | .... | ..... | 24 " 36 | 10 " 14 | 140 | 8 |
| | | | | | | | 9 | 12.6 | | | | | 24 " 42 | 10 " 14 | 140 | 8 |
| | | | | | | | 10 | 14.0 | Use figures in last four | | | | 24 " 42 | 10 " 14 | 140 | 8½ |
| 36 | 34 | 2½ | 0.97 | 4.0 | 25.0 | 1.67 | 8 | 13.6 | column s for 30 inch and | | | | 30 " 36 | 10 " 16 | 160 | 8½ |
| | | | | | | | 9 | 15.3 | 36-inch boilers | | | | 30 " 42 | 10 " 18 | 180 | 8½ |
| | | | | | | | 10 | 16.9 | ..... | ..... | .... | ..... | 30 " 42 | 10 " 18 | 180 | 9 |
| | | | | | | | 11 | 18.6 | ..... | ..... | .... | ..... | 30 " 48 | 10 " 20 | 200 | 9 |
| | | | | | | | 12 | 20.9 | ..... | ..... | .... | ..... | 30 " 48 | 10 " 20 | 200 | 9½ |
| 42 | 34 | 3 | 1.44 | 5.3 | 30.2 | 2.0 | 9 | 18.5 | 36 by 36 | 10 by 20 | 180 | 9 | 36 " 42 | 10 " 20 | 200 | 8½ |
| | | | | | | | 10 | 20.5 | 36 " 36 | 10 " 20 | 180 | 9½ | 36 " 42 | 10 " 20 | 200 | 9 |
| | | | | | | | 11 | 22.5 | 36 " 36 | 10 " 20 | 180 | 10½ | 36 " 48 | 10 " 25 | 250 | 9 |
| | | | | | | | 12 | 24.5 | 36 " 36 | 10 " 20 | 180 | 11½ | 36 " 48 | 10 " 25 | 250 | 9½ |
| | | | | | | | 13 | 26.5 | 36 " 42 | 10 " 22 | 200 | 11 | 36 " 48 | 10 " 25 | 250 | 10½ |
| | | | | | | | 14 | 28.5 | 36 " 42 | 10 " 22 | 200 | 12 | 36 " 54 | 10 " 28 | 280 | 10½ |
| 48 | 44 | 3 | 1.86 | 7.2 | 38.4 | 2.56 | 10 | 30.4 | 42 " 36 | 10 " 22 | 200 | 11 | 42 " 48 | 10 " 28 | 280 | 9 |
| | | | | | | | 11 | 33.2 | 42 " 36 | 10 " 22 | 200 | 12 | 42 " 48 | 10 " 28 | 280 | 10 |
| | | | | | | | 12 | 35.7 | 42 " 42 | 10 " 25 | 220 | 11½ | 42 " 54 | 10 " 32 | 320 | 10 |
| | | | | | | | 13 | 38.3 | 42 " 42 | 10 " 25 | 220 | 12 | 42 " 54 | 10 " 32 | 320 | 10½ |
| | | | | | | | 14 | 40.8 | 42 " 42 | 10 " 25 | 220 | 12½ | 42 " 60 | 10 " 36 | 360 | 10½ |
| | | | | | | | 15 | 43.4 | 42 " 48 | 10 " 23 | 250 | 12 | 42 " 60 | 10 " 36 | 360 | 11 |
| | | | | | | | 16 | 45.9 | 42 " 48 | 10 " 23 | 250 | 12½ | 42 " 60 | 10 " 36 | 360 | 11 |
| 54 | 54 | 3 | 2.28 | 9.3 | 46.4 | 3.10 | 11 | 34.6 | 48 " 42 | 10 " 23 | 250 | 9½ | 48 " 54 | 10 " 38 | 380 | 8½ |
| | | | | | | | 12 | 37.7 | 48 " 42 | 10 " 28 | 250 | 10 | 48 " 54 | 10 " 38 | 380 | 9 |
| | | | | | | | 13 | 40.8 | 48 " 42 | 10 " 28 | 250 | 11 | 48 " 54 | 10 " 38 | 380 | 10 |
| | | | | | | | 14 | 43.9 | 48 " 42 | 10 " 23 | 250 | 12 | 48 " 54 | 10 " 38 | 380 | 10½ |
| | | | | | | | 15 | 47.0 | 48 " 48 | 10 " 33 | 290 | 11½ | 48 " 60 | 10 " 40 | 400 | 10 |
| | | | | | | | 16 | 50.1 | 48 " 54 | 10 " 38 | 320 | 12 | 48 " 60 | 10 " 40 | 400 | 11 |
| | 46 | 3½ | 2.67 | 8.8 | 46.3 | 3.10 | 17 | 53.0 | 48 " 54 | 10 " 38 | 320 | 12½ | 48 " 60 | 10 " 40 | 400 | 11½ |
| 60 | 72 | 3 | 3.04 | 11.2 | 59.6 | 4.0 | 12 | 48.4 | 54 " 48 | 10 " 38 | 320 | 10 | 54 " 60 | 12 " 40 | 460 | 9½ |
| | | | | | | | 13 | 52.4 | 54 " 48 | 10 " 38 | 320 | 10½ | 54 " 60 | 12 " 40 | 460 | 10 |
| | | | | | | | 14 | 56.4 | 54 " 48 | 10 " 38 | 320 | 12 | 54 " 60 | 12 " 40 | 400 | 11 |
| | | | | | | | 15 | 60.4 | 54 " 54 | 12 " 35 | 370 | 12 | 54 " 66 | 12 " 42 | 500 | 10½ |
| | | | | | | | 16 | 64.4 | 54 " 54 | 12 " 35 | 370 | 12½ | 54 " 66 | 12 " 42 | 500 | 11½ |
| | 64 | 3½ | 3.71 | 10.5 | 62.4 | 4.16 | 17 | 71.4 | 54 " 60 | 12 " 40 | 400 | 12½ | 54 " 72 | 12 " 48 | 550 | 11½ |
| | | | | | | | 18 | 75.6 | 54 " 60 | 12 " 40 | 400 | 13½ | 54 " 72 | 12 " 48 | 550 | 12 |
| 66 | 90 | 3 | 3.80 | 13.5 | 74.2 | 4.95 | 14 | 70.1 | 60 " 54 | 12 " 40 | 400 | 12 | 60 " 66 | 12 " 48 | 500 | 11 |
| | | | | | | | 15 | 75.0 | 60 " 60 | 12 " 44 | 450 | 12 | 60 " 72 | 12 " 52 | 620 | 11 |
| | | | | | | | 16 | 80.0 | 60 " 60 | 12 " 44 | 450 | 12½ | 60 " 72 | 12 " 52 | 620 | 12 |
| | 78 | 3½ | 4.52 | 12.6 | 75.2 | 5.10 | 17 | 86.0 | 60 " 60 | 12 " 44 | 450 | 13 | 66 " 72 | 12 " 56 | 670 | 11½ |
| | | | | | | | 18 | 91.1 | 60 " 60 | 12 " 44 | 450 | 13½ | 66 " 72 | 12 " 56 | 670 | 12 |
| | | | | | | | 19 | 96.2 | 60 " 66 | 12 " 48 | 500 | 13 | 66 " 72 | 12 " 56 | 670 | 12½ |
| | 62 | 4 | 4.32 | 12.4 | 69.2 | 4.60 | 20 | 93.1 | 60 " 66 | 12 " 48 | 500 | 13 | 66 " 72 | 12 " 56 | 670 | 12 |
| 72 | 114 | 3 | 4.81 | 15.7 | 92.5 | 6.16 | 14 | 87.4 | 66 " 60 | 12 " 48 | 500 | 12 | 66 " 72 | 12 " 56 | 670 | 11½ |
| | | | | | | | 15 | 93.6 | 66 " 60 | 12 " 48 | 500 | 13 | 66 " 72 | 12 " 56 | 670 | 12 |
| | | | | | | | 16 | 99.7 | 66 " 60 | 12 " 48 | 500 | 14 | 72 " 72 | 12 " 62 | 740 | 12 |
| | 98 | 3½ | 5.75 | 15.0 | 93.0 | 6.20 | 17 | 106.4 | 66 " 66 | 12 " 52 | 540 | 13½ | 72 " 72 | 12 " 62 | 740 | 13 |
| | | | | | | | 18 | 112.6 | 66 " 66 | 12 " 52 | 540 | 14 | 72 " 72 | 12 " 62 | 790 | 13 |
| | | | | | | | 19 | 118.8 | 66 " 66 | 12 " 52 | 540 | 14½ | 72 " 72 | 12 " 62 | 790 | 14 |
| | 72 | 4 | 5.02 | 15.0 | 79.7 | 5.31 | 20 | 107.3 | 66 " 60 | 12 " 48 | 500 | 14½ | 72 " 72 | 12 " 62 | 740 | 13 |

the proportions and form of which are taken up in a following chapter.

As the horse power of a boiler depends upon its effective heating surface, it follows that with any given diameter and length of shell the power will vary with the size and number of tubes. If the

## TABLE VIII.

DIMENSIONS OF LIGHT SETTINGS FOR BOILERS USED IN HEATING.

| Dia. of boiler. | Add the figures given below to length of tubes, to find length of brick setting. | | Width of setting, 1 boiler. | | Width of setting, 2 boilers. | | Width of setting, 3 boilers. | | Width of setting, 4 boilers. | |
|---|---|---|---|---|---|---|---|---|---|---|
| In. | Ft. | In. | Ft. | In. | Ft. | In. | Ft. | In. | Ft. | In. |
| 30 | 3 | 2 | 5 | 8 | 9 | 8 | 13 | 8 | 17 | 8 |
| 36 | 3 | 4 | 6 | 2 | 10 | 10 | 15 | 6 | 20 | 2 |
| 42 | 3 | 4 | 6 | 8 | 11 | 10 | 17 | 0 | 22 | 2 |
| 48 | 3 | 10 | 7 | 2 | 12 | 10 | 18 | 6 | 24 | 2 |
| 54 | 3 | 10 | 7 | 8 | 14 | 0 | 20 | 4 | 26 | 8 |
| 60 | 3 | 10 | 8 | 2 | 15 | 0 | 21 | 10 | 28 | 8 |
| 66 | 3 | 10 | 9 | 10 | 17 | 8 | 25 | 6 | 33 | 4 |
| 72 | 3 | 10 | * 9 | 4 | 16 | 8 | 24 | 0 | 31 | 4 |
| | | | * 10 | 4 | 18 | 8 | 26 | 6 | 34 | 10 |
| | | | 9 | 10 | 17 | 8 | 25 | 0 | 32 | 10 |

* Upper figures to be used when width of grate equals diameter of boiler; lower figures when it is 6 inches less.

tubes are placed too close together and so near the shell as to interfere with the free circulation of the water, the efficiency of their heating surface will be impaired and the performance of the boiler will fall below its rating.

## TABLE IX.

DIMENSIONS OF HEAVY SETTINGS FOR POWER BOILERS.

| Dia. of boiler. | Add the figures given below to length of tubes, to find length of brick setting. | | Width of setting, 1 boiler. | | Width of setting, 2 boilers. | | Width of setting, 3 boilers. | | Width of setting, 4 boilers. | |
|---|---|---|---|---|---|---|---|---|---|---|
| In. | Ft. | In. | Ft. | In. | Ft. | In. | Ft. | In. | Ft. | In. |
| 30 | 3 | 6 | 5 | 8 | 9 | 8 | 13 | 8 | 17 | 8 |
| 36 | 3 | 8 | 6 | 10 | 11 | 8 | 16 | 6 | 22 | 4 |
| 42 | 3 | 8 | 7 | 4 | 12 | 8 | 18 | 0 | 23 | 4 |
| 48 | 4 | 2 | 7 | 10 | 13 | 8 | 19 | 6 | 25 | 4 |
| 54 | 4 | 2 | 9 | 0 | 15 | 8 | 22 | 4 | 29 | 0 |
| 60 | 4 | 2 | 9 | 6 | 16 | 8 | 23 | 10 | 31 | 0 |
| 66 | 4 | 2 | 10 | 0 | 17 | 8 | 25 | 4 | 33 | 0 |
| 72 | 4 | 2 | 10 | 6 | 18 | 8 | 26 | 10 | 35 | 0 |

The number and size of tubes given in Table VII. for boilers of different diameters have been found by experience to give satisfactory results, and may be used with safety. The sizes of grates given for different rates of combustion and evaporation will be

found convenient for reference. The sizes of uptake and smoke pipe in each case are proportioned for the corresponding size of grate and rate of combustion.

Tables VIII. and IX. give the over-all dimensions for boilers of different sizes with light and heavy settings, as called for in Table XXIX.

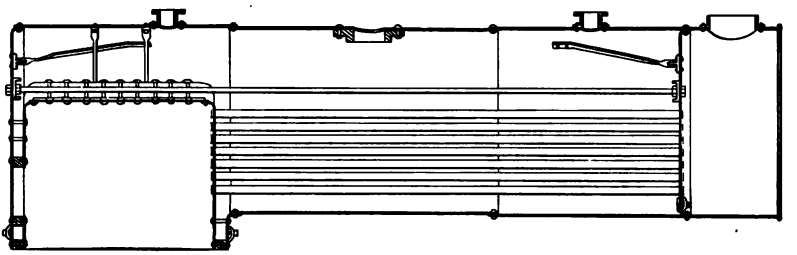


Fig. 2. Locomotive Type Boiler.

*Locomotive Boiler.*—Another form of tubular boiler in quite common use for stationary purposes is the "locomotive" type. This is an internally fired boiler, and consists of a cylindrical shell, called the barrel, attached to a fire box as in Fig. 2. The fire box proper is usually from three to four inches smaller

TABLE X.

DIMENSIONS OF LOCOMOTIVE TYPE BOILERS.

| Nominal horse power..... | 18 | 25 | 40 | 50 | 75 |
|---|---|---|---|---|---|
| Diameter of waist..... | 36 in. | 42 in. | 48 in. | 54 in. | 60 in. |
| Length over all..... | 13 ft. | 14 ft. 4 in. | 17 ft. 6 in. | 18 ft. 6 in. | 21 ft. |
| Height of boiler..... | 4 ft. | 4 ft. 8 in. | 5 ft. 4 in. | 5 ft. 10 in. | 6 ft. 6 in. |
| Number of tubes, 3 in. outside diameter..... | 28 | 38 | 49 | 60 | 80 |
| Length of tubes..... | 7 ft. | 8 ft. | 10 ft. 6 in. | 11 ft. | 13 ft. |
| Area through tubes..... | 1.23 sq. ft. | 1.65 sq. ft. | 2.27 sq. ft. | 2.47 sq. ft. | 3.38 sq. ft. |
| Length of furnace..... | 48 in. | 50 in. | 54 in. | 60 in. | 60 in. |
| Width of furnace..... | 30 in. | 36 in. | 42 in. | 48 in. | 54 in. |

than the outer shell, being secured to the latter by means of stay-bolts. The spaces between the inner and outer shells are called the water-legs. The tubes are expanded into the front of the fire box and into the rear head of the barrel. Table X. gives the principal dimensions for standard locomotive boilers.

This type of boiler requires a brick ash-pit, the walls of which act as a support for the furnace. The other end of the boiler rests in a cast iron saddle, supported upon either a brick pier or an iron column. The shell and furnace are usually covered with a lagging of asbestos or magnesia.

*Vertical Fire-Tube Boiler.*— A boiler of this type is shown in Fig. 3. Since it is internally fired it requires no setting except a foundation, and is frequently used where floor space is limited and the power required is small. These boilers are commonly built in sizes

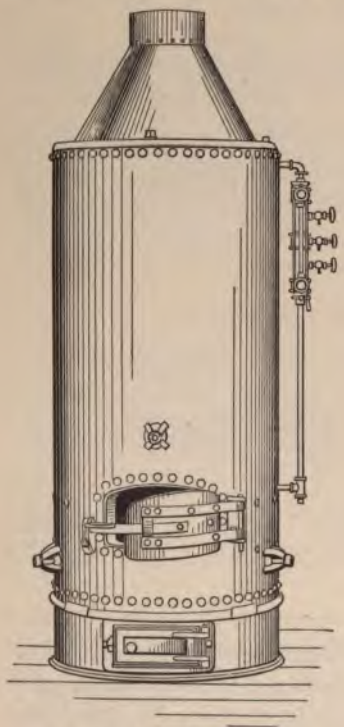


Fig. 3. Vertical Fire-Tube Boiler.

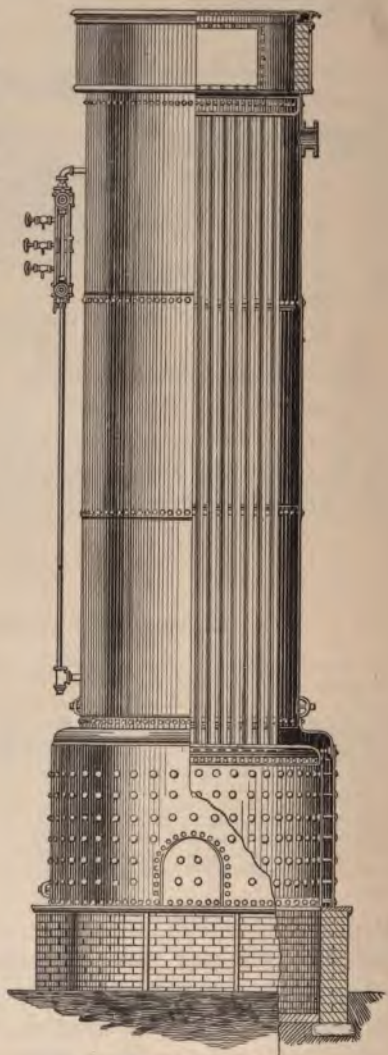


Fig. 4. Manning Boiler.

ranging from five to twenty-five horse power. Table XI. gives the principal dimensions.

*Manning Boiler.*—A sectional view of the Manning boiler is shown in Fig. 4. This is similar to the one just described, but is built in larger sizes. The general construction of the boiler is shown in the cut. The special features comprise the means for taking care of the expansion of the tubes and shell. This is

TABLE XI.

DIMENSIONS OF VERTICAL FIRE-TUBE BOILERS.

Rating — 15 square feet of heating surface per horse power.

| Diameter of shell. | Diameter of furnace. | No. of tubes 2 inches outside diam. | Area of tube opening. | Length of tubes. | Nominal horse power. | Height over all, including base and bonnet. | Diameter of smoke-pipe. |
|---|---|---|---|---|---|---|---|
| In. | In. | | Sq. ft. | Ft. In. | | Ft. In. | In. |
| 30 | 24 | 45 | .75 | 3 0 | 5.8 | 8 | |
| 30 | 24 | 45 | .75 | 3 6 | 6.5 | 8 6 | |
| 30 | 24 | 45 | .75 | 4 0 | 7.3 | 9 | 12 |
| 30 | 24 | 45 | .75 | 4 6 | 8. | 9 6 | |
| 30 | 24 | 45 | .75 | 5 0 | 8.7 | 10 | |
| 36 | 30 | 65 | 1.09 | 4 0 | 10.3 | 9 | |
| 36 | 30 | 65 | 1.09 | 4 6 | 11.4 | 9 6 | |
| 36 | 30 | 65 | 1.09 | 5 0 | 12.5 | 10 | 14 |
| 36 | 30 | 65 | 1.09 | 5 6 | 13.5 | 10 6 | |
| 36 | 30 | 65 | 1.09 | 6 0 | 14.6 | 11 | |
| 42 | 36 | 100 | 1.67 | 4 6 | 17. | 9 8 | |
| 42 | 36 | 100 | 1.67 | 5 0 | 18.7 | 10 2 | 16 |
| 42 | 36 | 100 | 1.67 | 5 6 | 20.3 | 10 8 | |
| 42 | 36 | 100 | 1.67 | 6 0 | 21.9 | 11 2 | |
| 48 | 42 | 120 | 2. | 5 0 | 22.5 | 10 2 | |
| 48 | 42 | 120 | 2. | 5 6 | 24.5 | 10 8 | 18 |
| 48 | 42 | 120 | 2. | 6 0 | 26.43 | 11 2 | |

provided for by means of a double flanged head connecting the barrel or cylindrical part of the boiler with the outside of the fire box. The double flange forms an expansion joint and also allows a larger diameter of fire box which gives the desired ratio of grate to heating surface. The crown sheet is well above the grate, thus giving ample room for the complete combustion of the gases within the furnace. Special handholes are provided in the different parts to allow for the proper cleaning and inspection of

the boiler. The products of combustion enter a smoke box at the top, from which they are conveyed to the chimney through a pipe which may be attached either at the top or side of the box. The water-level is so far below the upper tube sheet that there is ample steam space, and the highly heated tubes passing through it enable the boiler to furnish dry steam under practically all conditions of service.

Table XII. gives dimensions of the Manning boiler.

TABLE XII.

DIMENSIONS OF MANNING BOILERS.

| Diameter of shell. | Diameter of furnace, outside. | Diameter of furnace, inside. | Number of tubes. | Length of tubes. | Diameter of tubes, outside. | Horse power. | Total height of boiler from floor line to top of bonnet. |
|---|---|---|---|---|---|---|---|
| In. | In. | In. | | Ft. | In. | | Ft. In. |
| 38 | 55 | 48 | 90 | 11 | 2 | 36.8 | 19 4½ |
| 44 | 61 | 54 | 86 | 13 | 2½ | 52.1 | 21 4½ |
| 48 | 65 | 58 | 112 | 15 | " | 76.4 | 23 6½ |
| 50 | 67 | 60 | 124 | 15 | " | 84.2 | 23 8½ |
| 56 | 73 | 66 | 152 | 15 | " | 102.7 | 23 10½ |
| 61 | 79 | 72 | 184 | 15 | " | 123.9 | 24 1½ |
| 72 | 98 | 90 | 260 | 15 | " | 173.4 | 24 5 |

**Water-tube Boilers.**

*Aultman & Taylor Boiler (Babcock & Wilcox Type).*—This boiler has wrought-iron tubes placed in an inclined position as shown, with a horizontal steam and water drum above them. (Fig. 5.)

The tubes are connected with the drum by means of headers and pipes, nearly vertical, at each end. The drum is made up of heavy iron or steel plates, and is usually of the form shown. There are several patterns made for different classes of work; among them the "cross-drum," in which the drum is placed at the rear in a transverse position and connected directly with the rear row of vertical tubes. This pattern requires less head room and is especially adapted to low basements. The boiler is suspended from iron girders which rest on iron columns and is independent

of the brickwork. The fire is under the front end of the inclined tubes and the gases are guided by baffle-plates and bridge wall up between the tubes into the combustion chamber, which is under the drum; thence down through another section of tubes and then up again a second time, and to the chimney through an opening in the rear wall.

The tubes in the different rows are "staggered" so that the gases are broken up in passing among them and a large propor-

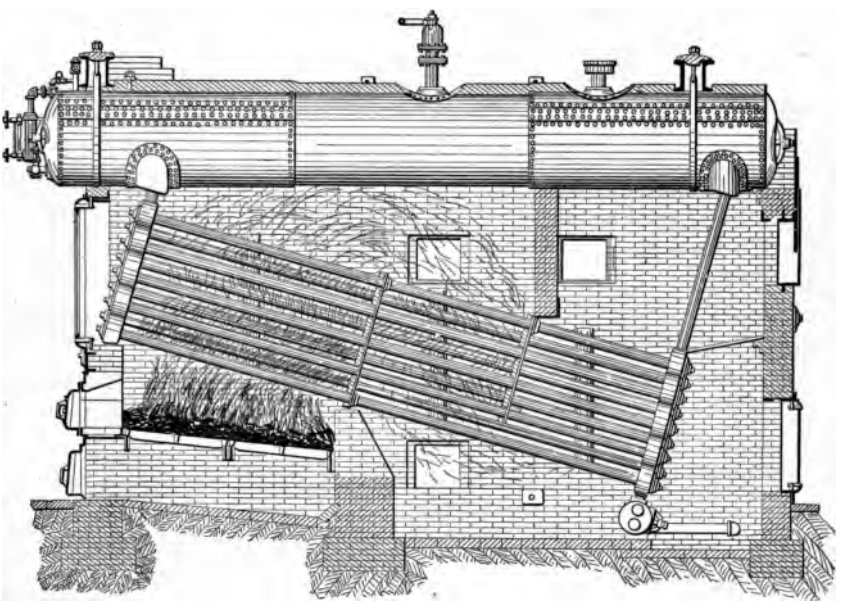


**Fig. 5. Aultman and Taylor Boiler.**
**(Babcock and Wilcox Type.)**

tion of their heat is absorbed. As the water in the tubes becomes heated, it rises toward the higher end, where it becomes partly converted into steam, and rises into the drum where the water and steam are separated. The water flows through the drum and down the tubes at the rear, this giving a circulation which is rapid and efficient. A mud drum of cast iron is connected with the tubes at their lowest point, forming a receptacle for sediment, from which it can be blown out from time to time as re-

quired. The steam is taken out at the top of the steam drum near the back end of the boiler, and to insure its dryness a perforated dry-pipe is connected with the nozzle inside the drum. The feed-water is discharged into the steam and water drum near the bottom and under a hood or deflector which tends to mix it with the hotter water flowing toward the rear of the boiler.

The Caldwell, Gill, National, and Standard are names of boilers similar in principle to the Aultman and Taylor, varying chiefly in details of construction. The construction of these boilers is such that the relative proportions may be varied to meet the requirements of any particular case.

The length of tubes usually varies from 10 to 18 feet; they are placed in vertical and horizontal rows, six inches on centers vertically and seven inches horizontally. Single boilers vary from five to 14 tubes in width and from seven to 14 or more in height. The tubes having an outside diameter of four inches, present a heating surface of one square foot for each foot in length.

Table XIII. gives the horse power and approximate over-all dimensions for a number of the more common sizes. This table applies to the regular pattern with *inclined* headers. The height depends upon the number of tubes in the vertical rows. For other sizes than those given in the table, add or subtract six inches for each vertical row, as the case may be.

For *vertical* header boilers, subtract two feet six inches from the lengths given in the table.

For *cross drum* boilers, use the lengths in the table, and for the heights subtract four feet from the tabulated heights. When more than 14 sections in width are required, two boilers should be used, set in a battery. The width of the battery will be twice that of a single boiler, less 17 inches. Spaces of at least two feet should be left at one side and at the rear of single boilers, and at both sides of double boilers, for reaching the cleanout doors, and space should be left in front for drawing the tubes. The smoke connections are taken from the rear of the setting.

*Heine Boiler.*—Fig. 6 shows a section of the Heine boiler which is similar in many respects to the one just described. It is a water-tube, but not a sectional boiler. The tubes are of wrought iron, expanded into the inside faces of the water legs

at either end. The parallel plates of the water legs are supported by stay-bolts passing through them, and are joined at the top to the shell of the drum by flanged and riveted joints. The heads of the drum are spherical and require no staying. A hand-

## TABLE XIII.

DIMENSIONS OF AULTMAN AND TAYLOR BOILERS WITH INCLINED HEADERS.

Rating—10 square feet of heating surface per horse power.

| Length of tubes, | Number of tubes high | Horse power per vertical section | Number of sections wide | Total horse power | Length of setting, | Width of setting | Height to top of steam outlet |
|---|---|---|---|---|---|---|---|
| Ft. | | | | | Ft. | Ft. In. | Ft. In. |
| 12 | 7 | 8.4 | 6 | 50.4 | 17 | 6 8 | 15 |
| | | | 8 | 67.2 | | 7 10 | |
| | | | 10 | 84.0 | | 9 0 | |
| | | | 12 | 100.8 | | 10 2 | |
| | | | 14 | 117.6 | | 11 4 | |
| | 9 | 10.8 | 6 | 64.8 | | 6 8 | 15 6 |
| | | | 8 | 86.4 | | 7 10 | |
| | | | 10 | 108.0 | | 9 0 | |
| | | | 12 | 129.6 | | 10 2 | |
| | | | 14 | 151.2 | | 11 4 | |
| 14 | 7 | 9.8 | 6 | 58.8 | 19 | 6 8 | 15 |
| | | | 8 | 78.4 | | 7 10 | |
| | | | 10 | 98.0 | | 9 0 | |
| | | | 12 | 117.6 | | 10 2 | |
| | | | 14 | 137.2 | | 11 4 | |
| | 9 | 12.6 | 6 | 75.6 | | 6 8 | 15 6 |
| | | | 8 | 100.8 | | 7 10 | |
| | | | 10 | 126.0 | | 9 0 | |
| | | | 12 | 151.2 | | 10 2 | |
| | | | 14 | 176.4 | | 11 4 | |
| 16 | 7 | 11.2 | 8 | 89.6 | 21 | 7 10 | 15 |
| | | | 10 | 112.0 | | 9 0 | |
| | | | 12 | 134.4 | | 10 2 | |
| | | | 14 | 156.8 | | 11 4 | |
| | 9 | 14.4 | 8 | 91.2 | | 7 10 | 15 6 |
| | | | 10 | 144.0 | | 9 0 | |
| | | | 12 | 172.8 | | 10 2 | |
| | | | 14 | 201.6 | | 11 4 | |
| 18 | 7 | 12.6 | 8 | 100.8 | 23 | 7 10 | 15 |
| | | | 10 | 126.0 | | 9 0 | |
| | | | 12 | 151.2 | | 10 2 | |
| | | | 14 | 176.4 | | 11 4 | |
| | 9 | 16.2 | 8 | 129.6 | | 7 10 | 15 6 |
| | | | 10 | 162.0 | | 9 0 | |
| | | | 12 | 194.4 | | 10 2 | |
| | | | 14 | 226.8 | | 11 4 | |

hole is placed over the end of each tube in the head plate, giving access to the tube and a chance for removal. The products of combustion pass over the bridge wall into the combustion chamber, then back toward the front between two rows of tiling, which are supported upon the upper and lower rows of tubes, then upward

through the space between the upper row of tiling and the front water leg, and back underneath the water and steam drum, and are finally taken off at the rear, through an iron bonnet or hood. The boiler is supported on brickwork by the two water legs. The feedwater enters the front head of the drum and is discharged into the open end of a cylinder or mud drum, having the same

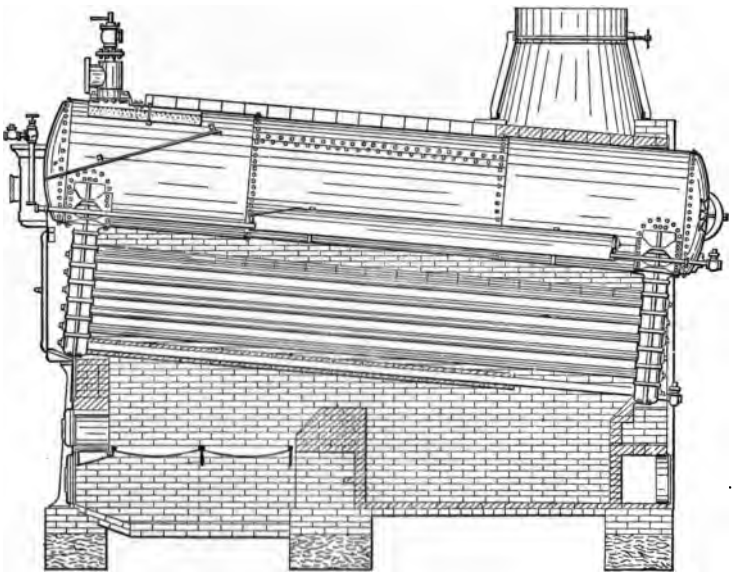


Fig. 6. Heine Boiler.

inclination as the tubes. The sediment collects in the lower end of this drum and can be discharged through the blow-off pipe, which is connected at this point. A second blow-off or drain is connected with the rear water leg at its lowest point. The water becoming hot in the mud drum rises and flows in a reverse direction toward the open end, then passes in a thin sheet to the rear of the water drum, where it enters the water leg and flows from here through the tubes to the front of the boiler. While in the tubes, it is partially converted into steam, which rises through the water at the front of the drum into the steam space. A deflecting plate is here provided to prevent the water from being carried into the perforated steam pipe above. The Franklin,

Keeler, Edge Moor, and Geary boilers have the same general arrangement of tubes and steam drums, while the Zell boiler has features common to both the Aultman and Taylor and the Heine

## TABLE XIV.

### DIMENSIONS OF HEINE BOILERS.

Rating—10 square feet of heating surface per horse power.

| Horse power | Length of tubes | Width of furnace | Square feet heating surface | Length of setting | Height | Width of setting |
|---|---|---|---|---|---|---|
| | Ft. | In. | | Ft. In. | Ft. In. | Ft. In. |
| 69 | 14 | 46 | 688 | 15 4 | 12 10 | 7 2 |
| 90 to 126 | 16 to 18 | 53 | 908 to 1263 | 17 4 to 19 4 | 13 5 to 14 0 | 7 9 |
| 127 to 171 | 16 to 18 | 60 | 1273 to 1714 | 17 4 to 19 4 | 13 6 to 14 1 | 8 4 |
| 142 to 191 | 16 to 18 | 67 | 1420 to 1918 | 17 4 to 19 4 | 14 8½ to 15 3½ | 8 11 |
| 156 to 210 | 16 to 18 | 74 | 1564 to 2106 | 17 4 to 19 4 | 14 2 to 14 9 | 9 6 |
| 171 to 230 | 16 to 18 | 81 | 1716 to 2306 | 17 4 to 19 4 | 15 10 to 16 10 | 10 1 |
| 225 to 293 | 16 to 18 | 88 | 2244 to 2931 | 17 4 to 19 4 | 16 8 to 17 3 | 10 8 |
| 242 to 316 | 16 to 18 | 95 | 2417 to 3160 | 17 4 to 19 4 | 18 3 to 18 10 | 11 3 |
| 281 to 367 | 16 to 18 | 109 | 2808 to 3669 | 17 4 to 19 4 | 15 7 to 16 2 | 12 5 |
| 298 to 389 | 16 to 18 | 116 | 2978 to 3892 | 17 4 to 19 4 | 15 8 to 16 3 | 13 0 |
| 372 to 478 | 16 to 18 | 123 | 3724 to 4785 | 17 4 to 19 4 | 17 1¼ to 17 8¼ | 13 7 |
| 391 to 500 | 16 to 18 | 130 | 3912 to 5002 | 17 4 to 19 4 | 17 1¼ to 17 8¼ | 14 2 |

boilers. These boilers range from 69 to 500 horse power each. Any number may be placed side by side in a battery without passageways between them.

To find the width of a battery of boilers of any given size, multiply the width of furnace given in Table XIV. by the number to be installed and add 20 inches for each outside wall and 27 inches for each division wall. If the space is limited, 20-inch division walls can be used. A passageway of at least two feet should be left at the rear of the setting for reaching the cleanout doors,

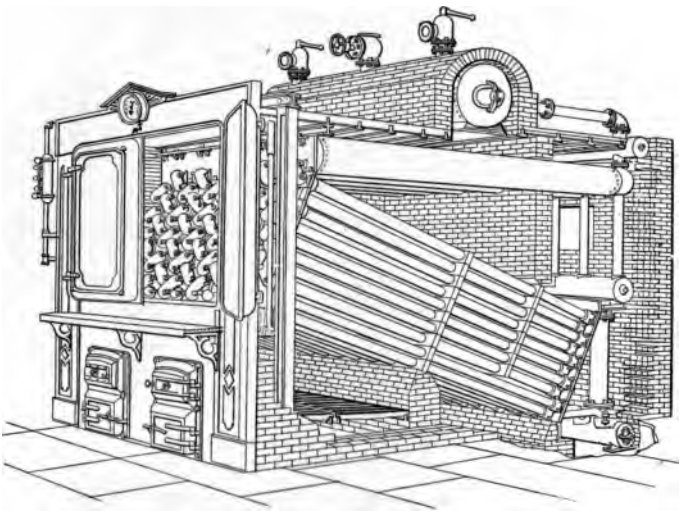


**Fig. 7. Root Boiler.**

and a space in front for drawing the tubes. The smoke connections are on top near the rear. Table XIV. gives the principal dimensions for a variety of sizes.

*Root Boiler.*—The Root boiler, Fig. 7, is made up of 4-inch wrought-iron tubes expanded in pairs into cast-iron headers at both ends. Each tube is connected to one in the pair above it by a return bend, so that a continuous flow of water is obtained from the bottom to the top of the section. The boiler is made up of several of these vertical sections placed side by side. The tubes in the sections are "staggered," and provision is made for unequal expansion. Each section has its separate overhead drum to receive its discharge of steam and water. At the rear of each overhead drum is a vertical pipe leading to a cross drum be-

neath, which serves as a common connection for all of the sections. The feed water enters this drum and mixes with the hot water from above. The cross drum is also connected by vertical pipes with another drum below and parallel to it, which serves as a mud drum. The feed water first falls into the mud drum, then rises through the tubes to the overhead drums, where the steam separates and finds its way to the large steam drum which is shown across the top of the boiler. Dry steam is taken from the

TABLE XV.

DIMENSIONS OF ROOT BOILERS, CROSS-DRUM PATTERN.

Rating—10 square feet of heating surface per horse power

| Number of tubes wide. | Number of tubes high. | Horse power. | Length of setting. | Width of setting. | Approximate height to top of steam outlet. |
|---|---|---|---|---|---|
| Fifteen-foot tubes. | | | | | |
| | | | Ft. In. | Ft. In. | Ft. In. |
| 4 | 6 | 36 | 19 2 | 5 2 | 13 0 |
| 6 | 7 | 63 | 19 4 | 6 6 | 13 6 |
| 8 | 8 | 96 | 19 7 | 7 10 | 14 0 |
| 10 | 9 | 135 | 19 9 | 9 2 | 15 0 |
| 12 | 10 | 180 | 19 11 | 10 6 | 15 6 |
| 14 | 12 | 252 | 20 4 | 11 10 | 17 0 |
| Eighteen-foot tubes. | | | | | |
| 6 | 7 | 76 | 22 2 | 7 2 | 14 6 |
| 8 | 8 | 115 | 22 5 | 8 6 | 15 0 |
| 10 | 9 | 162 | 22 7 | 9 10 | 16 0 |
| 12 | 10 | 216 | 22 9 | 11 2 | 16 6 |
| 14 | 12 | 302 | 23 2 | 12 6 | 18 0 |
| 16 | 13 | 375 | 23 4 | 13 10 | 18 6 |

steam drum, the water line being at about the middle of the steam and water drums below. The gases pass among the tubes three times before reaching the chimney. A steam jet is used for cleaning the tubes, and numerous openings with sliding doors are provided for this purpose, as well as to give access for inspection and repairs.

These boilers are built in sizes up to 400 horse power, ranging from four to 16 tubes in width and from six to 13 in height. Each row of tubes adds approximately six and one-half inches to

the height and eight inches to the width. The tubes are four inches in diameter and the lengths commonly used run from 15 to 18 feet. Space should be left at the rear and one side of a single boiler for reaching the cleanout doors. When two boilers are set in a battery a passageway should be left at each side. Space should be provided in front for drawing the tubes. Table XV. gives the over-all dimensions for a few standard sizes of the cross-drum pattern shown in Fig 7.

The width of two of these boilers set in a battery is equal to twice the width of a single boiler, less 9 inches for 15-foot

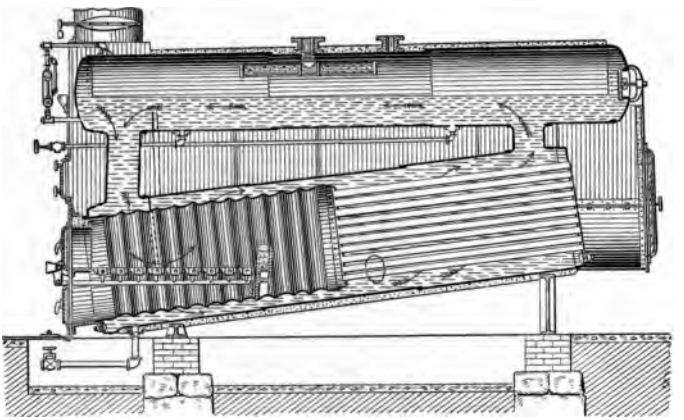


**Fig. 8. Robb-Mumford Boiler.**

tubes, and less 17 inches for 18-foot tubes as given in the above table. Various combinations of width, length and height other than those given can be made up to meet special conditions.

The smoke connections are taken from the rear.

*Robb-Mumford Boiler.*—The Robb-Mumford boiler, shown in Fig. 8, is an internally fired water-tube boiler. It consists of two cylindrical shells, the lower one containing a round furnace and tubes, and the upper one forming the steam drum, the two being connected by two necks. The lower shell has an incline of about 1 inch per foot from the horizontal, for the purpose of promoting circulation and draught, and also for convenience in washing out the lower shell. Combustion takes place in the

furnace, which is surrounded entirely by water, and the gases after leaving the furnace, pass through the tubes and return between the lower and upper shells, (this space being enclosed by a steel casing), to the outlet at the front of the boiler. The water, together with the steam formed by contact with the furnace and tubes, circulates rapidly up the rear neck into the steam drum, where the steam is released, the water passing along the upper drum towards the front of the boiler and down the front neck; a semi-circular baffle plate around the furnace causing the down-flowing water to circulate to the lowest part of the lower shell under the furnace.

The outer casing which incloses the space between the lower and upper shells, including the rear smoke box and smoke outlet, as well as the front and back, is constructed of steel plate, with angle iron stiffeners, the various sections being bolted together for convenient removal. The inside of the steel case including the rear smoke chamber is lined with asbestos air cell blocks fitted in between the angle iron stiffeners. The top of the upper drum and bottom of the lower shell are also covered with non-conducting material after the boiler is erected.

As every part of the boiler is cylindrical except the tube sheets, no staying is required. The furnace is of the corrugated type for high pressures, or with Adamson expansion joints for lower

TABLE XVI.

DIMENSIONS OF ROBB-MUMFORD BOILERS.

Rating — 10½ square feet of heating surface per horse power.

| Horse power. | Total width. | Total length. | Height to Steam outlet. |
|---|---|---|---|
| | Ft. | Ft. In. | Ft. In. |
| 50 | 54 | 14 6 | 9 6 |
| 65 | 54 | 18 6 | 9 6 |
| 80 | 60 | 18 6 | 10 10 |
| 100 | 60 | 21 0 | 10 10 |
| 125 | 66 | 21 0 | 11 8 |
| 150 | 72 | 21 0 | 12 8 |
| 200 | 79 | 23 0 | 13 10 |

pressures, providing perfectly for unequal expansion and contraction, and requiring no staying. The water in the boiler is comparatively small in volume, and well subdivided, so that a rupture is no more dangerous than in a sectional boiler.

Table XVI. gives the over-all dimensions of the standard sizes of this type of boiler. The boilers, when set in battery, are placed side by side, so that the width in any case may be found by simply multiplying the width of a single boiler by the number used. The large open spaces underneath and between the lower and upper drums give access to the handholes and all the interior parts of the boiler. A space of about 3 feet should be left at the rear for reaching the cleanout doors.

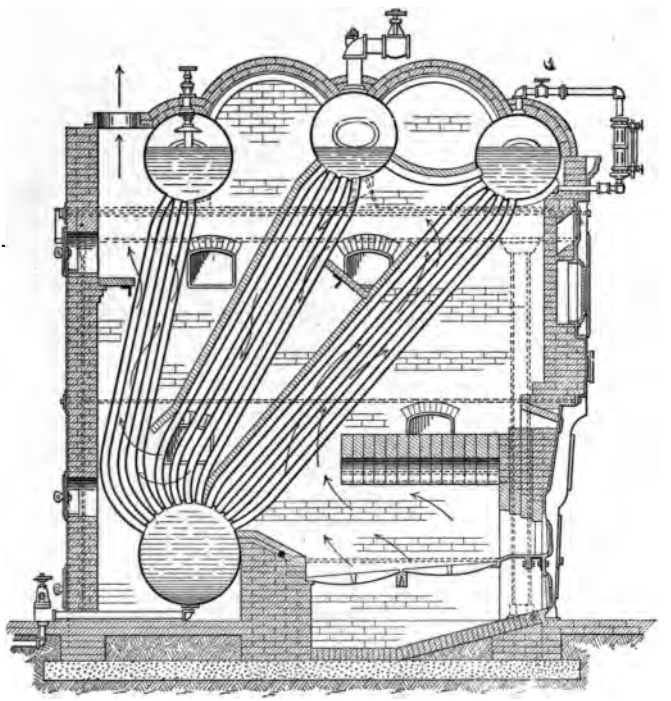


**Fig. 9. Stirling Boiler.**

*Stirling Boiler.*—The Stirling boiler, Fig. 9, consists of three steam and water drums at the top and a large mud drum at the bottom. All of the upper drums are connected by steam circulating tubes, and the front and middle drums are connected by water circulating tubes also. The feed water enters the rear upper drum and steam is taken off from the middle drum. The

lower drum acts as a receptacle for sediment and is connected with the blow-off pipe. Each set of tubes is separated from the other by fire-brick tile, so arranged that the gases rise among the first set, are then guided downward through the second set and

## TABLE XVII.

### DIMENSIONS OF STIRLING BOILERS.

Rating — 10 square feet of heating surface per horse power.

| Horse power | Class "A" Width | | Horse power | Class "B" Width | | Horse power | Class "B" (low) Width | |
|---|---|---|---|---|---|---|---|---|
| | Single | Battery | | Single | Battery | | Single | Battery |
| 115 | 7 ft. | 13 ft. | 47 | 5 ft. 6 in. | 10 ft. | 47 | 5 ft. 6 in. | 10 ft. |
| 143 | 8 " | 15 " | 57 | 6 " | 11 " | 57 | 6 " | 11 " |
| 172 | 9 " | 17 " | 66 | 6 " 6 " | 12 " | 66 | 6 " 6 " | 12 " |
| 201 | 10 " | 19 " | 75 | 7 " | 13 " | 75 | 7 " | 13 " |
| 230 | 11 " | 21 " | 86 | 7 " 6 " | 14 " | 86 | 7 " 6 " | 14 " |
| 258 | 12 " | 23 " | 115 | 9 " | 17 " | 115 | 9 " | 17 " |
| 287 | 13 " | 25 " | 143 | 10 " 6 " | 20 " | 143 | 10 " 6 " | 20 " |
| 316 | 14 " | 27 " | 172 | 12 " | 23 " | 172 | 12 " | 23 " |
| 345 | 15 " | 29 " | 198 | 13 " 6 " | 26 " | 198 | 13 " 6 " | 26 " |
| 373 | 16 " | 31 " | 226 | 15 " | 29 " | 226 | 15 " | 29 " |
| 402 | 17 " | 33 " | 258 | 16 " 6 " | 32 " | 258 | 16 " 6 " | 32 " |
| | | | 287 | 18 " | 35 " | 287 | 18 " | 35 " |
| 16 feet deep<br>18 feet $7\frac{3}{16}$ inches high | | | 14 feet deep<br>16 feet high | | | 14 feet deep<br>12 feet $3\frac{3}{16}$ inches high | | |

| Horse power | Class "E" Width | | Horse power | Class "F" Width | | Horse power | Class "N" Width | |
|---|---|---|---|---|---|---|---|---|
| | Single | Battery | | Single | Battery | | Single | Battery |
| 99 | 7 ft. | 13 ft. | 207 | 9 ft. | 17 ft. | 173 | 7 ft. | 13 ft. |
| 124 | 8 " | 15 " | 241 | 10 " | 19 " | 216 | 8 " | 15 " |
| 148 | 9 " | 17 " | 276 | 11 " | 21 " | 260 | 9 " | 17 " |
| 173 | 10 " | 19 " | 310 | 12 " | 23 " | 303 | 10 " | 19 " |
| 198 | 11 " | 21 " | 345 | 13 " | 25 " | 347 | 11 " | 21 " |
| 223 | 12 " | 23 " | 379 | 14 " | 27 " | 390 | 12 " | 23 " |
| 247 | 13 " | 25 " | 414 | 15 " | 29 " | 433 | 13 " | 25 " |
| 272 | 14 " | 27 " | 448 | 16 " | 31 " | 477 | 14 " | 27 " |
| 297 | 15 " | 29 " | 483 | 17 " | 33 " | 520 | 15 " | 29 " |
| 321 | 16 " | 31 " | 517 | 18 " | 35 " | 564 | 16 " | 31 " |
| 346 | 17 " | 33 " | | | | 607 | 17 " | 33 " |
| 371 | 18 " | 35 " | | | | 650 | 18 " | 35 " |
| 16 feet 8 inches deep<br>15 feet 6 inches high | | | 16 feet 9 inches deep<br>20 feet $11\frac{1}{4}$ inches high | | | 18 feet 9 inches deep<br>24 feet $10\frac{3}{4}$ inches high | | |

then rise among the third set, and are taken off at the rear. The feed water as stated, enters the rear upper drum, then passes down the rear tubes to the mud drum, and during its passage is heated to within a few degrees of that in the front tubes and

moves in a direction opposite to that of the furnace gases, which pass into the stack at the point where the coolest water enters the boiler.

These boilers are made up in a great variety of forms to meet almost any requirement as regards the available space. Table XVII. gives some of the more common sizes. There are, however, intermediate sizes between those in the table, and also a num-

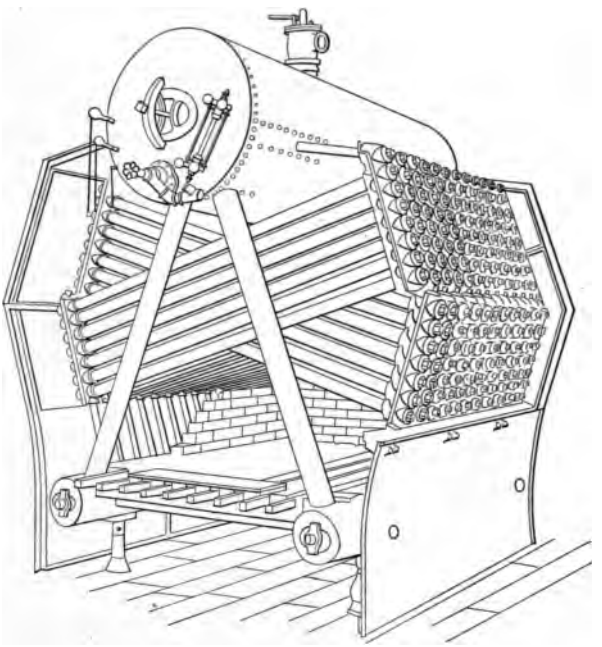


Fig. 10. Worthington Boiler.

ber of additional classes running principally to larger sizes. The widths given in the table are for a single boiler, and for two set in a battery. Space should be left at the rear and one side of the single boilers and at both sides of each battery for reaching the cleanout doors.

The smoke connections are taken from the top near the rear of the setting.

*Worthington Boiler.*—Fig. 10 shows the Worthington boiler with the outside casing removed. This is a water-tube boiler of the sectional class. It requires a relatively small space compared with the amount of grate and heating surface. The furnace extends under the entire boiler and the whole interior construction is accessible for cleaning and repairs. Each tube is straight and is expanded into the headers at each end. The tubes are arranged directly over the furnace in oppositely inclined sections several

TABLE XVIII.

DIMENSIONS OF WORTHINGTON BOILERS.

END FIRED BOILERS.

| Horse power. | Length over all. | Horse power. | Length over all. |
|---|---|---|---|
| Width over all 6 ft. 8 in.; height to top of drum 8 ft. 4 in. | | | |
| | Ft. In. | | Ft. In. |
| 41 | 6 8 | 58 | 8 3 |
| 45 | 7 1 | 62 | 8 7 |
| 49 | 7 5 | 67 | 8 11 |
| 54 | 7 10 | | |
| Width over all 8 ft. 9 in.; height to top of drum 10 ft. 1 in. | | | |
| 75 | 7 11 | 109 | 9 10 |
| 84 | 8 4 | 117 | 10 3 |
| 92 | 8 10 | 125 | 10 9 |
| 100 | 9 4 | | |

SIDE FIRED BOILERS.

| | | | |
|---|---|---|---|
| Width over all 8 ft. 9 in.; height to top of drum 10 ft. 1 in. | | | |
| 42 | 6 0 | 117 | 10 3 |
| 59 | 6 11 | 125 | 10 9 |
| 84 | 8 4 | 142 | 11 9 |
| 100 | 9 4 | | |
| Width over all 10 ft. 0 in.; height to top of drum 11 ft. 6 in. | | | |
| 64 | 7 0 | 178 | 12 10 |
| 75 | 7 7 | 189 | 13 5 |
| 87 | 8 2 | 201 | 14 0 |
| 121 | 9 11 | 235 | 15 9 |
| 133 | 10 6 | 246 | 16 4 |
| 144 | 11 1 | 258 | 16 11 |

tubes high. By this arrangement the whole heating surface is exposed to the full effect of the fire so that the movement of the water and the consequent evaporation is rapid. The water is fed into the large drum located at the top, and descends through the water legs, placed outside the furnace, to the mud drums at the base. It then passes through the tube connections into the lower headers, thence through the tubes over the fire into the upper headers, and then through the tube connections into the steam and water drums, where the steam is separated from the water and

taken off at the top of the drum. The headers are made of steel or iron, according to the service required, and are arranged in the boiler close together, forming complete side walls. Outside of the furnace, opposite the end of each tube, is a handhole of proper size to admit a tube or tube expander. The caps over the handholes are exposed for examination when the side doors of the casing are opened, and by removing these caps the inside of the tubes can be cleaned or inspected. The mud drums extend through the casing and are provided with handhole plates accessible from the outside. The only brick used in the setting except in the foundation walls, are those in the fire-brick lining of the furnace. The whole boiler, except the steam and water drum, is enclosed in a plate metal casing.

Table XVIII. gives the over-all dimensions of some of the different sizes of the Worthington boiler. This is made in two patterns, called the "end-fired" and "side-fired." In the former the tubes run across the boiler, and space must be left at one side or the other for drawing the tubes. In the side-fired boiler they run lengthwise, and can be drawn from the front. When placed in a battery it is better to use the side-fired type, as with these it is not necessary to leave spaces between them for drawing the tubes.

Spaces should be left at the sides and rear of both single boilers and batteries for reaching the cleanout doors. The smoke connections are made at the top.

*Cahall Vertical Boiler.* This is a water-tube boiler consisting of two drums arranged one above the other and connected with 4-inch tubes as in Fig. 11. The tubes are vertical and perfectly straight, and are expanded into the drums at each end. The upper or steam drum has an opening through its center for the discharge of the waste gases, which, in passing over the plates of the drum, give up part of their heat to the steam within, thereby tending to superheat it slightly. The water line in the upper drum is about 2 feet above the bottom of the drum, the drum itself being about 7 feet high inside. This gives a clear space of about 5 feet between the surface of the water and the steam outlet, which prevents the carrying over of water with the steam

An external circulating pipe connects with the upper drum just below the water level and is carried down outside the brickwork and connected with the lower drum just below the tube sheet.

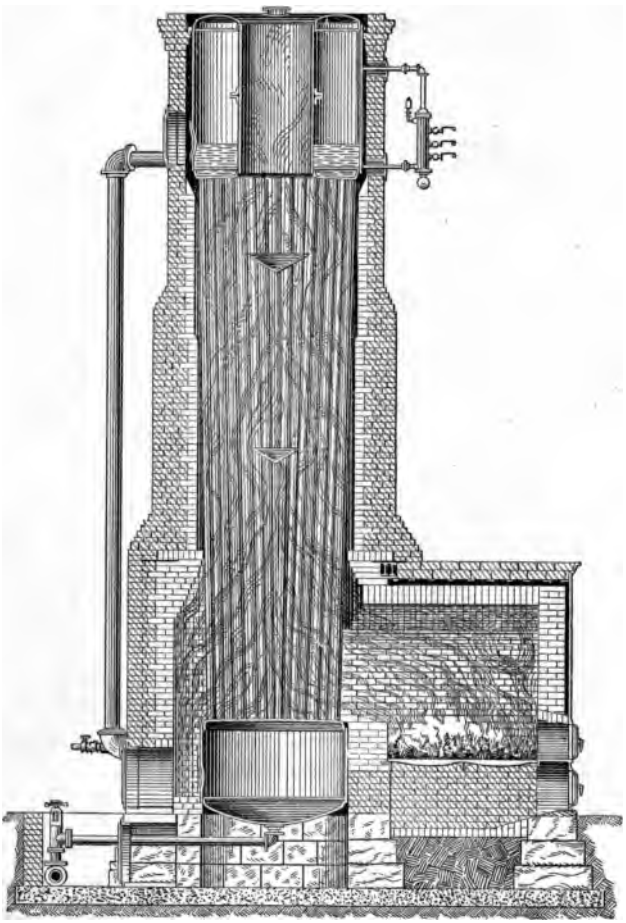


**Fig. 11. Cahall Vertical Boiler.**

The fact that there is no steam in the circulating pipe causes the water which it contains to have a considerably greater specific gravity than that within the tubes; this condition produces a

rapid circulation upward through the tubes and downward through the external pipe. The boiler rests upon four iron brackets riveted to the lower, or mud drum, which are in turn supported upon four piers of the foundation, thus carrying the entire structure without contact with the brickwork, and allowing freedom of expansion without straining the setting.

## TABLE XIX.

DIMENSIONS OF CAHALL VERTICAL BOILERS.

| Horse power | 60 | | 75 | | 100 | | 125 | | 150 | | 175 | | 200 | | 250 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ft. | In. | Ft. | In. | Ft. | In. | Ft. | In. | Ft. | In. | Ft. | In. | Ft. | In. | Ft. | In. |
| Diam. of steam drum | | 54 | | 54 | | 66 | | 66 | | 72 | | 72 | | 80 | | 80 |
| Diam. of mud drum | | 42 | | 42 | | 54 | | 54 | | 60 | | 60 | | 68 | | 68 |
| Number of tubes | 40 | | 40 | | 64 | | 64 | | 80 | | 80 | | 108 | | 108 | |
| Diam. of tubes | | 4 | | 4 | | 4 | | 4 | | 4 | | 4 | | 4 | | 4 |
| Length of tubes | 14 | | 15 | | 16 | | 16 | | 18 | | 21 | | 18 | | 22 | |
| Length of setting | 11 | 9 | 12 | 0 | 12 | 9 | 13 | 3 | 15 | 4 | 15 | 10 | 16 | 7 | 17 | 7 |
| Width of setting | 8 | 0 | 8 | 0 | 9 | 8 | 9 | 8 | 10 | 8 | 10 | 8 | 11 | 8 | 11 | 8 |
| Height to steam outlet | 23 | 5 | 27 | 5 | 25 | 1 | 28 | 10 | 29 | 0 | 32 | 0 | 29 | 0 | 33 | 0 |

Table XIX. gives the over-all dimensions for this type of boiler. A space of about 18 inches should be left at the rear of a single boiler for the circulating pipe, but if two or more boilers are set in a battery, this should be increased to 36 inches or more for bringing out the blow-off pipes and reaching the cleanout doors. When two boilers are set in a battery the width is equal to twice that of a single boiler, less 26 inches, and the width of an intermediate boiler in a battery of more than two is equal to that of a single boiler set alone, less 26 inches.

The smoke connections are taken from the top.

*The Figures in the Preceding Tables* cover the extreme dimensions of the boilers when set. They are not intended to replace the exact dimensions, which should always be obtained from the makers for any particular case, especially if the available space is limited. They will, however, be found convenient for reference and are sufficiently accurate for much preliminary work. The dimensions given have been furnished by the makers or have been taken from published tables.

**Cast-Iron Boilers for Heating.**

*Cast-Iron Sectional Boilers.*—There are many forms of cast-iron sectional boilers which are used principally for low-pressure heating in dwelling houses and other buildings of moderate size.

*Mercer Boiler.*—The Mercer boiler, Fig. 12, illustrates the principle upon which many of these boilers are constructed. It is made up of slabs or sections, each one of which is connected by nipples with headers or drums at the top and sides. The gases from the fire pass backward and forward through flues formed by openings in the sections, as shown by the arrows, and are

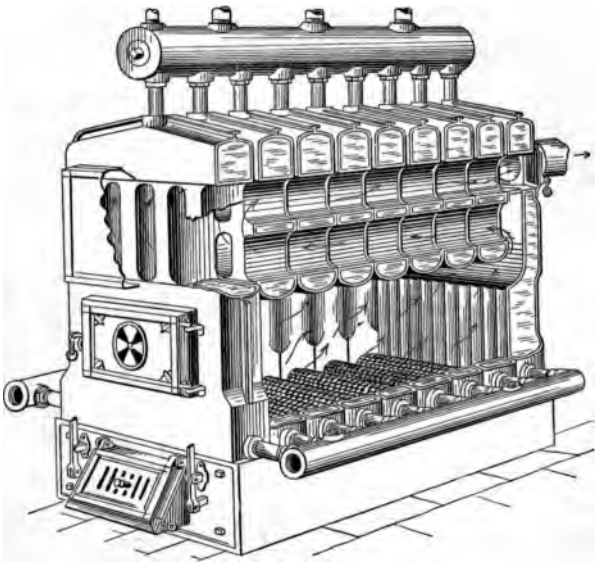


**Fig. 12. Mercer Boiler.**

finally taken off at the rear of the boiler. The forms for steam and water are practically the same, except for the attachment of gauges, water glass, etc., in the case of steam boilers. In using boilers of this type care must be taken not to use too many sections in a single boiler, for if the grate is made too long, the fire on the rear portion cannot be properly cared for, and the efficiency of the furnace will be impaired.

If more capacity is required, it is better to use two short boilers rather than a single long one. In general, the grate in this type of boiler should not be over 4 feet in length, or 5 feet at the most.

In boilers of small size the grate usually extends to the last section as shown in Fig. 12, but for large sizes with a good chimney draft, a bridge wall section may be used, thus shortening the grate and increasing the ratio between the heating and grate surface. If this is done, the rate of combustion must be in-

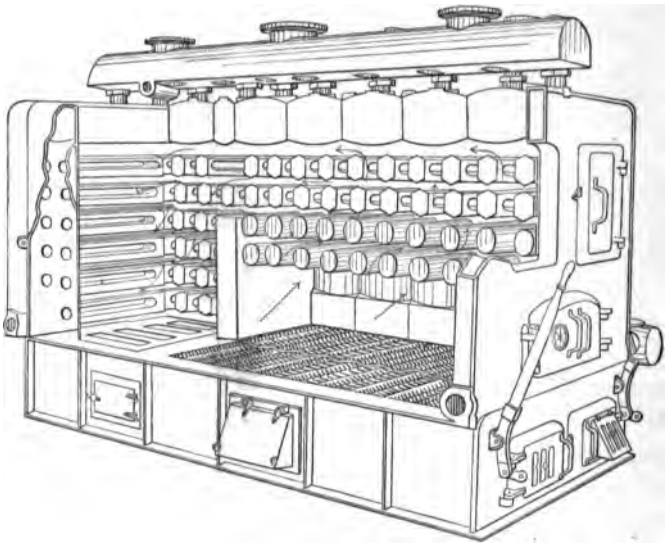


Fig. 13. Gurney Boiler.

creased in the same proportion so that the weight of coal burned per square foot of *heating surface* will remain the same.

*Gurney Boiler.*—Fig. 13 shows the Gurney sectional boiler arranged with a bridge wall as just described. This is a drum boiler, with each section having its independent supply and return connections.

*Model Boiler.*—The Model boiler in Fig. 14 is made up of sections which increase its width instead of the length. This type of boiler has a large proportion of its heating surface ex-

posed to the direct heat of the fire, and the travel of the gases before reaching the smoke pipe is somewhat less than in the other forms just described. As the width of the boiler is increased more fire doors are provided, so that all parts of the grate can be easily reached, whatever the size. These boilers have no drum connecting with the sections, but instead, each section connects with the adjacent one through openings at the top and bottom as shown.

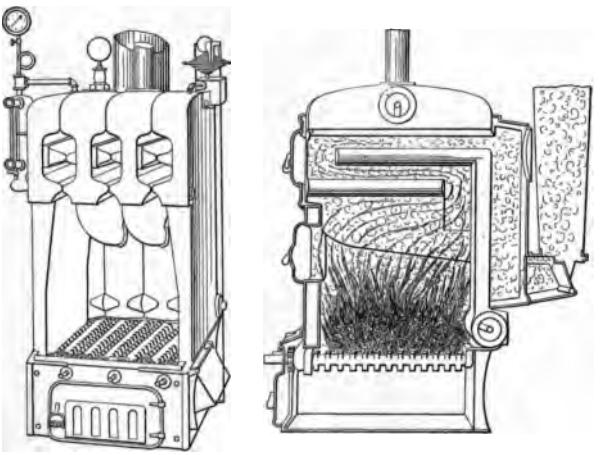


Fig. 14. Model Boiler.

*Ideal Boiler.*—The Ideal boiler, Fig. 15, illustrates a common form of the cast-iron sectional type. It is built of sections which increase its length like the Mercer and Gurney, but the connections between them are like those in the Model; that is, through openings at the top and bottom.

*Magee Boiler.*—The Magee, Fig. 16, represents a typical form of small boiler for dwelling-house work.

*In General.*—There are many different designs of cast-iron boilers for low pressure steam and hot-water heating, but the ones shown serve to illustrate the distinctive features of some of the more important makes. Boilers having a drum connected by nipples with each section usually give dryer steam and hold a

steadier water line than the second form, especially when forced above their normal capacity. The steam in passing through the openings between successive sections in order to reach the outlet is apt to carry with it more or less water and to partially choke the openings and thus produce an uneven pressure in different parts of the boiler. This is especially noticeable when two or

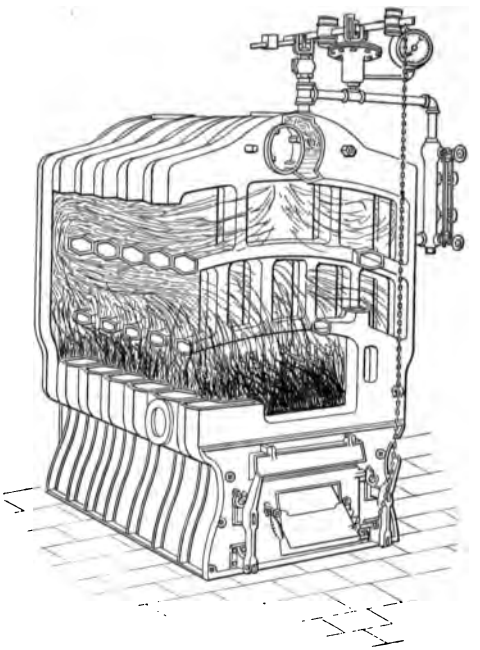


Fig. 15. Ideal Boiler.

more boilers are connected together in a battery. In the case of hot-water boilers this objection disappears.

In order to adapt this type of boiler to steam work the openings between the sections should be of good size, with an ample steam space above the water line, and the nozzles for the discharge of steam should be located at frequent intervals.

A pressure of from 1 to 5 pounds is usually carried on these boilers, depending upon the outside temperature and the size of

the piping connecting them with the radiators. The usual setting is simply a covering of some kind of non-conducting material like plastic magnesia or asbestos. The smaller cast-iron sec-

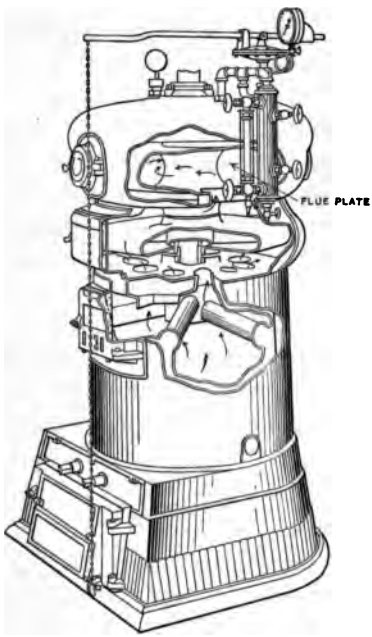



**Fig. 16. Magee Boiler.**

tional boilers vary so greatly in size and shape for the same capacity that it is best to refer to the manufacturers' catalogues for dimensions.

## CHAPTER V.

### DESIGN OF TUBULAR BOILERS.

When water-tube boilers, or others of special form are to be used, the engineer has little to do with their design. Before selecting a boiler, however, he should satisfy himself as to the reliability of the manufacturers, make a careful examination of the extent and arrangement of the heating surfaces, and familiarize himself as much as possible with all the leading points in its design and construction. With boilers of this type the problem is one of selection rather than one of design.

When horizontal fire-tube boilers are to be used they should, if possible, be made to order from plans and specifications drawn up by the engineer, covering the more important points relating to their general proportions and construction. Space will not allow a detailed discussion of this subject, but a few simple rules and formulæ, together with various tables, will be sufficient to enable one to design a plain tubular boiler in all its essential parts, such as the size and number of tubes, type and dimensions of riveted joints, bracing, etc.

*Materials.*—Most boilers at the present time are made of "open hearth" steel. The usual requirements are that the plates shall have a tensile strength of not less than 55,000, nor more than 60,000 pounds per square inch of section, with not less than 56 per cent of ductility as indicated by contraction of area at point of fracture; and an elongation of 25 per cent in a length of 8 inches.

The heads are made of "flange" steel, which is an extra quality of open-hearth steel, made with special reference to toughness and ductility.

The breaking load for mild steel in tension may be taken as 55,000 pounds per square inch, while the resistance to crushing in riveted joints is about 95,000 pounds.

Wrought-iron plates are rarely used except when especially called for. They are more ductile and require less care in working than steel, but otherwise have no advantage over steel plates,

which are more easily obtained and stronger. The ultimate strength of wrought iron may be taken as 45,000 pounds per square inch for tension and 75,000 pounds per square inch for compression.

Rivets are made of iron or steel of a quality and strength similar to that used for the plates. Rivets are subjected to a shearing stress in addition to tension and compression. The ultimate resistance to shearing may be taken as 44,000 pounds for steel and 38,000 for wrought iron.

All stays and fastenings which require welding should be of the best quality of wrought iron. Where welding is not necessary mild steel may be used instead.

Manhole frames and covers are usually made of cast iron or cast steel, although wrought iron and mild steel are often used for this purpose. The finer grades of cast iron commonly known as "gun iron" have a tensile strength varying from 20,000 to 25,000 pounds; the resistance to crushing is about three times as great for small blocks, while somewhat less for larger pieces.

*Factor of Safety.*—In designing the different parts of any structure, a certain allowance in strength must be made to overcome any flaw which may be present in the material, and to offset any sudden load which may be thrown upon the structure when in use. This allowance is called a *factor of safety* and varies according to the material used and the kind of load to be supported. A factor of safety of 6 is recommended for tubular boilers in general use, although 5 is considered safe for thoroughly constructed boilers of good design.

*Drilling and Punching Plates.*—It is usual in the best class of work to drill the rivet holes after the plates are in place. When the plates are punched, the metal between the holes is weakened. Plates that are first punched and then rolled to form are often distorted so that the holes come unfair for riveting; this defect is avoided when the holes are drilled with the plates in position.

### General Proportions.

The diameter and general proportions of a boiler are determined by the horse power required, the pressure to be carried, and to

some extent by the available space in the boiler room. As the shell plates in this type of boiler are exposed directly to the fire they should not in general be over ½ inch in thickness, which limits the diameter for any given pressure. Another factor bearing upon the diameter is the tube area; this is usually made at least one-seventh of the grate area.

*Tubes.*—The sizes of tubes most commonly used are those having outside diameters of 2½, 3, 3½, and 4 inches. A common rule for determining the diameter of tubes to be used for any given length of boiler is to allow 1 inch in diameter for each 5 feet in length for anthracite coal, and for each 4 feet in length for bituminous.

The number and arrangement of the tubes is a matter of much importance; they should not be crowded together too closely, as increasing the number beyond a certain limit decreases their efficiency as heating surface. There should be a clear space of 1 inch between the tubes both vertically and horizontally, with a vertical space of 2 inches at the center. Tubes should not be placed nearer than 3 inches to the shell, owing to the liability of grooving, due to unequal expansion of shell and tubes. A clear space of 6 inches or more should be left between the tubes and the bottom of the shell to serve as a mud drum.

Table VII. gives a suitable number of tubes for boilers of different diameters, as well as other useful data in connection with boiler design.

*Steam Space.*—In heating boilers it is customary to make the steam space about one third of the contents of the boiler after deducting the space occupied by the tubes. For power boilers it is more common to compute it by some rule depending upon the amount of steam used by the engine. A common method is to make it equal to the volume of steam used by the engine in 20 seconds. The normal water line should be from 4 to 6 inches above the upper row of tubes; 5 inches is usual for boilers 54 and 60 inches in diameter.

### Strength of Shell.

*Thickness of Shell.*—The relations between the thickness of

shell, steam pressure, and diameter of boiler, are expressed in the following equations:—

$$t = \frac{d \times p \times F}{2 \times S \times E}$$

$$p = \frac{2 \times S \times t \times E}{d \times F}$$

$$d = \frac{2 \times S \times t \times E}{p \times F}$$

in which

$t$ = the thickness of shell plates, in inches

$p$ = steam pressure, in pounds per sq. inch

$d$ = diameter of boiler, in inches

$F$ = the factor of safety.

$S$ = the ultimate strength of the shell plates, in pounds per sq. inch.

$E$ = the efficiency of the riveted joints

The following may be taken as the average values of $E$ for different types of riveted joints:

Single riveted lap joint, 45 per cent.

Double riveted lap joint, 56 per cent.

Triple riveted lap joint, 70 per cent.

Double riveted butt joint, 70 per cent.

Triple riveted butt joint, 80 per cent.

Example. What is the thickness of plate required for a cylindrical steam boiler 60 inches in diameter, to carry a pressure of 100 lbs. per sq. inch, the boiler to be constructed of steel having a tensile strength of 60,000 lbs. per sq. inch, double riveted butt joint, and factor of safety 5?

[illegible]

[illegible]

factors of safety. In using this table in the design of new boilers, an additional amount must be added to offset the effects of corrosion as already stated. Boiler heads are usually made from 1/16 to 1/8 of an inch thicker than the shell plates.

## TABLE XX.

### WORKING PRESSURES FOR TUBULAR BOILERS.

**Assumed strength of plates, 55,000 pounds; assumed efficiency of joints, single lap 55 per cent, double lap 70 per cent, double butt 80 per cent, triple butt 87 per cent.**

| Diameter of boiler, inches | Thickness of shell, inches | Factor of safety 6 | | | | Factor of safety 5 | | | | Factor of safety 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Kind of joint | | | | Kind of joint | | | | Kind of joint | | | |
| | | Single lap | Double lap | Double butt | Triple butt | Single lap | Double lap | Double butt | Triple butt | Single lap | Double lap | Double butt | Triple butt |
| 30 | 1/4 | 82 | 107 | 123 | 137 | 98 | 128 | 147 | 163 | 123 | 160 | 184 | 204 |
| | 5/16 | 103 | 134 | 155 | 172 | 124 | 161 | 186 | 205 | 155 | 201 | 232 | 257 |
| | 3/8 | 124 | 161 | 186 | 205 | 148 | 192 | 221 | 245 | 185 | 240 | 277 | 307 |
| | 7/16 | 145 | 188 | 217 | 240 | 173 | 225 | 259 | 286 | 216 | 281 | 324 | 358 |
| | 1/2 | 165 | 215 | 248 | 275 | 198 | 257 | 296 | 328 | 247 | 321 | 370 | 410 |
| 36 | 1/4 | 69 | 90 | 103 | 115 | 82 | 107 | 123 | 137 | 103 | 134 | 154 | 171 |
| | 5/16 | 86 | 112 | 129 | 143 | 103 | 134 | 154 | 171 | 129 | 168 | 193 | 214 |
| | 3/8 | 103 | 134 | 155 | 171 | 123 | 160 | 185 | 204 | 154 | 200 | 231 | 255 |
| | 7/16 | 120 | 157 | 181 | 201 | 144 | 187 | 216 | 239 | 180 | 234 | 270 | 299 |
| | 1/2 | 138 | 180 | 207 | 229 | 165 | 214 | 247 | 274 | 206 | 268 | 309 | 342 |
| 42 | 1/4 | 59 | 76 | 88 | 98 | 70 | 91 | 105 | 17 | 88 | 114 | 132 | 146 |
| | 5/16 | 73 | 96 | 110 | 122 | 88 | 115 | 132 | 145 | 110 | 143 | 165 | 183 |
| | 3/8 | 88 | 115 | 133 | 147 | 105 | 137 | 158 | 175 | 132 | 171 | 198 | 219 |
| | 7/16 | 103 | 134 | 155 | 170 | 123 | 160 | 185 | 204 | 154 | 200 | 231 | 255 |
| | 1/2 | 118 | 154 | 178 | 197 | 142 | 184 | 212 | 235 | 177 | 230 | 265 | 294 |
| 48 | 1/4 | 52 | 67 | 77 | 86 | 62 | 80 | 92 | 102 | 77 | 100 | 115 | 128 |
| | 5/16 | 64 | 84 | 96 | 106 | 77 | 100 | 115 | 127 | 96 | 125 | 144 | 159 |
| | 3/8 | 78 | 100 | 116 | 129 | 93 | 120 | 139 | 154 | 16 | 150 | 174 | 193 |
| | 7/16 | 90 | 118 | 135 | 150 | 108 | 140 | 162 | 179 | 135 | 176 | 203 | 224 |
| | 1/2 | 104 | 135 | 155 | 172 | 124 | 162 | 185 | 205 | 155 | 202 | 232 | 257 |
| 54 | 1/4 | 46 | 59 | 68 | 76 | 54 | 70 | 82 | 90 | 68 | 88 | 102 | 113 |
| | 5/16 | 58 | 75 | 86 | 96 | 69 | 90 | 103 | 114 | 86 | 112 | 129 | 143 |
| | 3/8 | 69 | 90 | 103 | 115 | 82 | 107 | 123 | 137 | 103 | 134 | 154 | 171 |
| | 7/16 | 80 | 105 | 120 | 134 | 96 | 125 | 144 | 159 | 120 | 156 | 180 | 199 |
| | 1/2 | 92 | 119 | 137 | 152 | 109 | 142 | 163 | 182 | 137 | 178 | 205 | 227 |
| 60 | 1/4 | 41 | 53 | 62 | 68 | 49 | 64 | 73 | 82 | 62 | 80 | 92 | 102 |
| | 5/16 | 51 | 67 | 77 | 86 | 62 | 81 | 93 | 102 | 77 | 100 | 116 | 128 |
| | 3/8 | 62 | 81 | 93 | 102 | 74 | 96 | 110 | 122 | 93 | 120 | 138 | 153 |
| | 7/16 | 72 | 94 | 109 | 120 | 87 | 112 | 129 | 143 | 108 | 140 | 162 | 170 |
| | 1/2 | 82 | 108 | 124 | 137 | 99 | 128 | 148 | 164 | 124 | 160 | 185 | 205 |
| 66 | 1/4 | 38 | 49 | 56 | 62 | 45 | 58 | 67 | 74 | 56 | 73 | 84 | 93 |
| | 5/16 | 47 | 61 | 70 | 78 | 56 | 73 | 84 | 93 | 70 | 91 | 105 | 116 |
| | 3/8 | 56 | 73 | 84 | 92 | 67 | 87 | 100 | 113 | 84 | 109 | 126 | 139 |
| | 7/16 | 66 | 85 | 98 | 109 | 78 | 102 | 118 | 130 | 98 | 127 | 147 | 163 |
| | 1/2 | 75 | 98 | 113 | 125 | 90 | 117 | 134 | 149 | 112 | 146 | 168 | 186 |
| 72 | 1/4 | 35 | 45 | 51 | 57 | 41 | 54 | 61 | 68 | 52 | 67 | 77 | 85 |
| | 5/16 | 43 | 56 | 65 | 71 | 51 | 67 | 77 | 85 | 65 | 84 | 96 | 107 |
| | 3/8 | 51 | 67 | 77 | 85 | 61 | 80 | 92 | 102 | 77 | 100 | 116 | 127 |
| | 7/16 | 60 | 78 | 91 | 101 | 72 | 94 | 108 | 119 | 90 | 117 | 135 | 145 |
| | 1/2 | 69 | 90 | 104 | 114 | 82 | 107 | 123 | 137 | 103 | 134 | 155 | 171 |

*Riveted Joints.*—For all ordinary work it is more convenient to use proportions for the various types of riveted joints which experience has proved to be satisfactory rather than to prepare

new designs. Tables XXI. and XXII. give the different dimensions for the more common forms of riveted joints as recommended by the Hartford Steam Boiler Inspection and Insurance

TABLE XXI.*

DOUBLE AND TRIPLE RIVETED LAP JOINTS.

| Thickness of plate. | Diameter of rivets. | Pitch of rivets. | Distance between rows of rivets. | Edge of plate to center of rivets. | Pitch of girth seam rivets. | Efficiency of joint. |
|---|---|---|---|---|---|---|
| Double riveted. | | | | | | |
| 1/4 | 1 1/8 | 2 7/8 | 1 1/4 | 1 1/8 | 2 1/8 | 74% |
| 5/16 | 1 1/8 | 2 7/8 | 1 1/4 | 1 1/8 | 2 1/8 | 72% |
| 3/8 | 1 1/8 | 3 1/4 | 2 3/16 | 1 1/4 | 2 3/8 | 70% |
| 7/16 | 1 1/8 | 3 1/4 | 2 3/16 | 1 1/4 | 2 3/8 | 70% |
| 1/2 | 1 | 3 1/4 | 2 1/4 | 1 1/4 | 2 1/16 | 69% |
| Triple riveted. | | | | | | |
| 1/4 | 3/4 | 3 | 2 | 1 1/16 | 2 1/16 | 77% |
| 5/16 | 1 1/8 | 3 1/4 | 2 1/16 | 1 1/4 | 2 1/4 | 76% |
| 3/8 | 1 1/8 | 3 1/4 | 2 3/16 | 1 1/4 | 2 1/4 | 75% |
| 7/16 | 1 1/8 | 3 1/4 | 2 1/4 | 1 1/4 | 2 1/4 | 75% |
| 1/2 | 1 1/8 | 3 1/16 | 2 1/8 | 1 1/2 | 2 1/2 | 75% |

* From Ryerson's *Monthly Journal.*

Company. In each case the pitch of the rivets is given for the girth seams, in which it is assumed that they are of the same diameter as in the longitudinal seams.

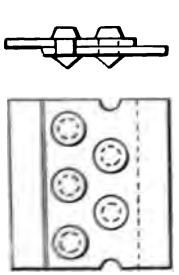


Fig. 17. Double Riveted Lap Joints.

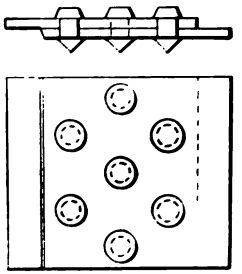


Fig. 18. Triple Riveted Lap Joints.

Girth seams are subjected to a stress due to the pressure upon the heads. It can be shown by a simple process, that this stress

for any given length of seam is just one half that upon an equal length of a longitudinal seam. A single riveted lap joint of usual dimensions has an efficiency of 50 per cent or more, so that

TABLE XXII.*

DOUBLE AND TRIPLE RIVETED BUTT JOINTS.

| Thickness of plate. | Diameter of rivets. | Pitch of rivets. | Width of outside butt strap. | Width of inside butt strap. | Thickness of butt straps. | Distance between rows of rivets. | Edge of butt straps to center of rivets. | Pitch of girth seam rivets. | Efficiency of joint. |
|---|---|---|---|---|---|---|---|---|---|
| Double riveted. | | | | | | | | | |
| 5/16 | 1 1/16 | 2 1/4 x4 1/8 | 4 1/8 | 9 | 1/4 | 2 1/8 | 1 1/16 | 2 1/4 | 89% |
| 3/8 | 1 1/8 | 2 3/8 x4 1/4 | 4 1/4 | 9 1/8 | 5/16 | 2 1/16 | 1 1/16 | 2 3/8 | 89% |
| 7/16 | 1 3/16 | 2 1/2 x4 3/8 | 5 1/8 | 10 1/4 | 3/8 | 2 1/8 | 1 1/16 | 2 1/2 | 88% |
| 1/2 | 1 1/4 | 2 5/8 x5 1/8 | 5 1/4 | 11 1/4 | 7/16 | 2 1/2 | 1 1/16 | 2 5/8 | 80% |
| Triple riveted. | | | | | | | | | |
| 5/16 | 1 1/16 | 3 1/4x6 1/2 | 9 1/2 | 14 | 1/4 | 2 1/8 | 1 1/16 | 2 1/16 | 88% |
| 3/8 | 1 1/8 | 3 1/4x6 1/2 | 9 1/2 | 14 1/4 | 5/16 | 2 3/16 | 1 3/16 | 2 1/4 | 87.5% |
| 7/16 | 1 3/16 | 3 1/4x6 1/2 | 10 1/8 | 15 1/8 | 3/8 | 2 1/4 | 1 3/16 | 2 7/16 | 86% |
| 1/2 | 1 1/8 | 3 1/4x7 1/2 | 11 | 16 1/2 | 7/16 | 2 1/8 | 1 1/16 | 2 1/2 | 86.6% |

*From Ryerson's *Monthly Journal*.

if all girth seams are made of this type, the boiler will be as strong relatively as the solid plates, in a direction parallel with its axis.

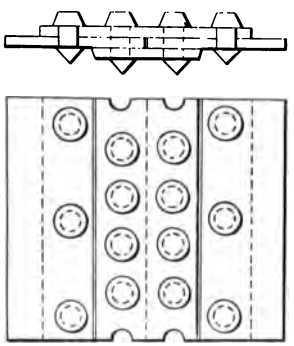


Fig. 19. Double Riveted

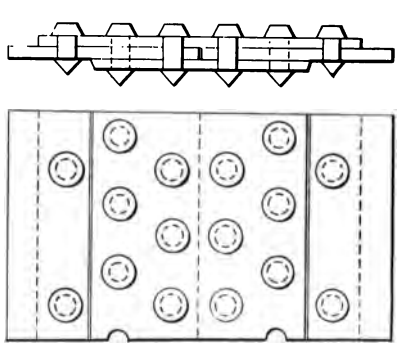


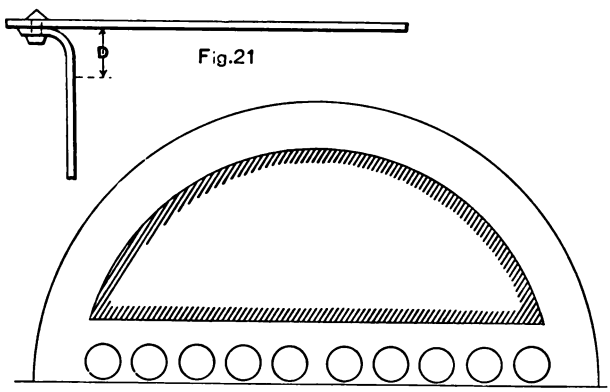
Fig. 20. Triple Riveted Butt Joints.

While lap joints are amply strong for the pressures indicated, when new, experience has shown that they have a tendency to

become weakened through extended use, due to a slight bending strain when under tension. For this reason it is better to use butt joints in all cases, unless it be for heating boilers carrying pressures less than 10 pounds, and even under these conditions the butt joint is to be recommended as an additional precaution.

### Boiler Bracing.

The surface to be supported by the braces is evidently that portion of each head above the tubes. In practice, however, it is not necessary to put in braces enough to sustain the whole of this area, for the reason that when the head is flanged and riveted to the shell a portion of it becomes stiff enough to carry the




**Indicating Part of Head Requiring Bracing.**

pressure without depending upon the braces. The distance that becomes self-supporting may be determined by the formula

$$D = \frac{4{,}484 \times T}{10 \times p} + 0.5$$

in which $D =$ the distance inward from the shell as indicated in Fig. 21, $T =$ the thickness of the head, and $p =$ the steam pressure per square inch.

When a boiler head has several rows of tubes expanded into it, a portion of the plate for a short distance above the upper

row is sufficiently supported by the tubes and it is usually safe to call this distance two thirds of that determined by the above formula. This leaves an area of the shape and location indicated by the shaded portion in Fig. 22 to be supported by the braces. Multiplying this area in square inches by the steam pressure per square inch gives the total load to be carried, and the size and number of braces must be proportioned accordingly.

*Computing Area of Segment.*—As a matter of convenience, the rule is given here for computing the area of the segment of a

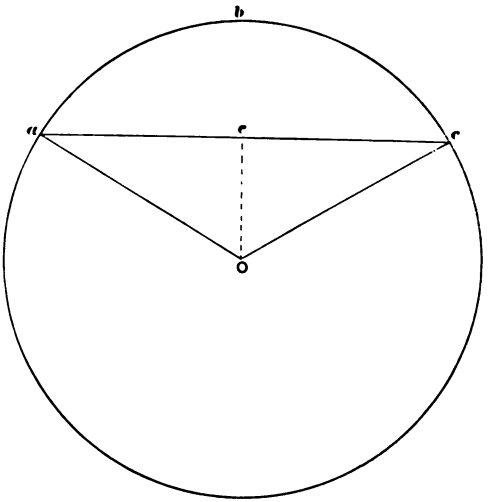



Fig. 23.

circle, which is necessary in finding the area of the shaded portion in Fig. 22.

First compute the area of the sector *o a b c* (Fig. 23), which is equal to the distance *a b c* measured around the shell, multiplied by one half the radius *o a*. Next compute the area of the triangle *o a c c*, which is equal to *a e* multiplied by *o e*, and subtract this from the area of the sector first found. The result will be the area of the segment. In making this computation the dimensions can be scaled from the drawing with sufficient accuracy.

*Points of Support.*—The maximum distance between the points of support, that is, the distance between the rivets fastening the head to the stays or to the stiffening bars, may be computed by the formula

$$p = \sqrt{\frac{C \times t^2}{P}}$$

in which

$p$ = the maximum distance between supports in inches.

$t$ = thickness of head, in sixteenths of an inch.

$P$ = steam pressure per square inch.

$C = 112$ for plates $\frac{7}{16}$ inches and under and 120 for plates over $\frac{7}{16}$ inches in thickness.

Assuming a steam pressure of 100 pounds per square inch, we find the values of $p$ to be as follows for different thicknesses of heads.

TABLE XXIII.

DISTANCES BETWEEN RIVETS FOR DIFFERENT THICKNESSES OF HEADS.

| "t" | "p" computed as above. | "p" Values used in practice. |
|---|---|---|
| In. | In. | In. |
| $\frac{7}{16}$ | 6.8 | 4 |
| $\frac{1}{2}$ | 7.8 | $4\frac{1}{2}$ |
| $\frac{9}{16}$ | 8.7 | $5\frac{1}{4}$ |
| $\frac{5}{8}$ | 9.8 | 6 |
| $\frac{11}{16}$ | 10.9 | $6\frac{1}{2}$ |

As the formula gives maximum values, it is customary to reduce the results somewhat in practice, so that the last column represents more nearly the actual distances used. There are two methods commonly employed for staying the heads of horizontal tubular boilers, known as "through bracing" and "crow-foot bracing."

*Through Bracing.*—Through bracing consists of rods passing through the entire length of the boiler, with heavy nuts and washers at the ends on the outside, and checknuts on the inside. Stiffening pieces of channel or angle iron are riveted to the heads to support them. Fig. 24 shows the general arrangement of the channel or angle irons and the ends of the rods or braces, together with a section of the stiffening bars and head. The upper bar in this case consists of a channel iron with an angle

riveted to its upper flange to give greater strength, while the lower bar is made up of two angles riveted to the head as shown. Where angles are used instead of channel iron, it is

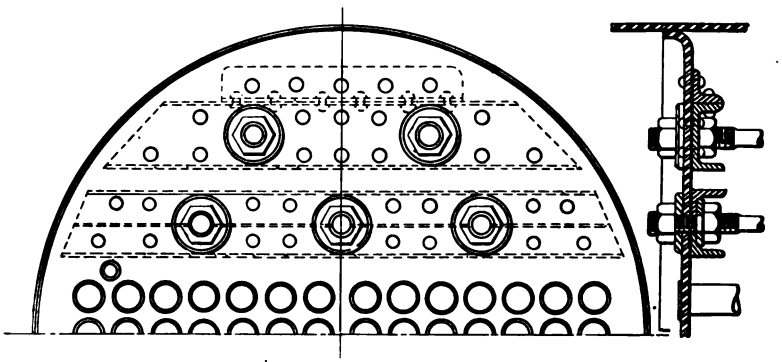


Fig. 24. Arrangement of Through Braces.

necessary to countersink slightly around the holes for the braces, in order to give a solid bearing for the washer which is placed under the checknut.

The outside washer is sometimes made of copper, slightly cup-shaped on the under side in order to make a tight joint

## TABLE XXIV.

SIZES OF BRACES AND STIFFENING BARS FOR 66- AND 72-INCH BOILERS.

| | In. | In. |
|---|---|---|
| Diameter of boiler | 66 | 72 |
| Distance from center of upper row of tubes to center of lower channel | 7½ | 8½ |
| Distance between centers of channels | 9 | 10 |
| Distance between lower braces | 15 | 16½ |
| Distance between upper braces | 19 | 20 |
| Channel bars, inches | 7x2.07x0.57 | Two 3½x2½x½ angles* |
| Angle, inches | 3½x3x½* | 3½x3x½* |
| Diameter of braces | 1½ | 1½ |
| Ends upset to | 2½ | 2½ |
| Diameter of channel rivets | 1 | 1 |
| Diameter of cast iron washers | 6 | 6 |
| Thickness of cast iron washers | 1 | 1 |

* Longer flange riveted to head.

around the edge. If cast-iron washers are used they should be embedded in red lead. When channel bars will give the required strength they are preferable to angles for stiffening pieces, but for high pressures the standard weights will in many cases be

found too light, and resort must be had to angle irons, of which there is a great variety to choose from. In this form of bracing the channel bars act as beams carrying the load due to the pull on the rivets, and the beams in turn are supported by the rods.

*Proportions for Through Bracing.*—Through bracing is commonly employed in boilers 66 and 72 inches in diameter; five braces being used and arranged as shown in Fig. 24. The distance between the upper braces should not be less than 17 or 18 inches owing to the difficulty of access for inspection if placed nearer together.

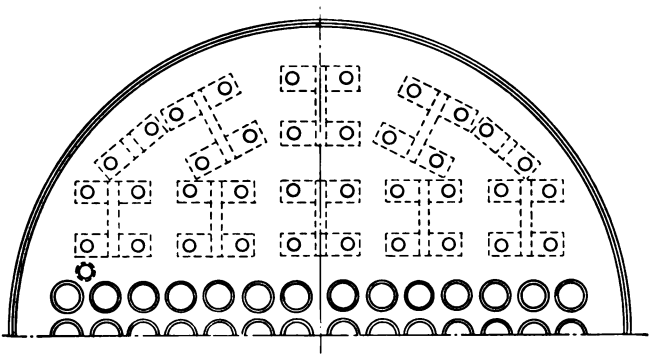


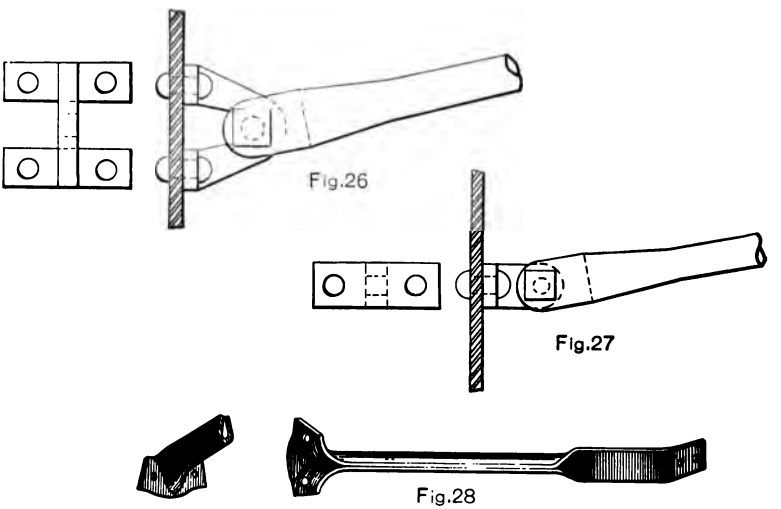
Fig. 25. Arrangement of Crow-foot Braces.

Table XXIV. gives the sizes of braces and stiffening bars for boilers 66 and 72 inches in diameter, having the number of tubes given in Table VII. Each boiler has five braces of mild steel proportioned to carry a pressure of 100 pounds per square inch with a factor of safety of 6. In this table, provision has been made for a reasonable amount of corrosion. The stiffening bars are usually spoken of as "channels" regardless of their makeup. The "angle" mentioned in the table is the angle iron riveted to the upper channel. The ends of the braces should be upset to such a size that the diameter at the root of the thread shall be equal to, or slightly greater than the body of the brace.

*Crow-foot Bracing.*—In this form of bracing the supported points are attached to a forging known as a "crow-foot." (See Fig. 25.) A diagonal stay with a forked head and pin is used to connect each crow-foot with the boiler shell, to which it is

fastened with two or more rivets. A crow-foot joined to the boiler head with four rivets as in Fig. 26 is called a double crow-foot; when only two rivets are used as in Fig. 27 it is called a single crow-foot. As the crow-foot and connecting rod are forgings, they are necessarily made of wrought iron containing welded joints, and should not carry a load of more than 5,000 pounds per square inch of section, measured at the weakest point.

*Solid Steel Braces* are now replacing the older form of crow-foot brace just described. These being of one piece, without




**Forms of Crow-foot Braces.**

welds, can be made of steel and therefore have a much greater tensile strength per square inch of section. A load of 10,000 pounds per square inch may be safely carried, as against 5,000 pounds with a welded brace. A common form is shown in Fig. 28. These braces are attached to the head and shell with two rivets in each end. The rivets connecting the brace with the head are in tension and those connecting it with the shell are subjected to a shearing stress and should be proportioned accordingly. No rivet, however, used in connection with braces of any kind should be less than ¾ inch in diameter.

Solid steel braces are commonly made of such size that the weakest part shall have a sectional area of at least one square inch. Two 1-inch rivets in each end of a brace of this size will give the connections equal strength with the body of the brace.

*Proportioning Diagonal Bracing.*—As the brace is carried back diagonally from the head to the shell, the load which it supports

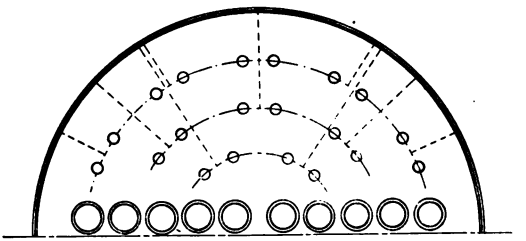


**Fig. 29. Layout of Rivets for Crow-foot Braces.**

perpendicular to the head is less than that along the axis of the brace. The angle which the brace makes with the shell should not in general be much over 20 degrees, in which case the supporting force at the head is only about 0.9 of that carried by the brace in the direction of its length.

In laying out the braces for a boiler we first find the area of the segment to be supported and multiply it by the steam pressure

TABLE XXV.

DATA FOR CROW-FOOT BRACING.

| Diameter of boiler | 42 in. | 48 in. |
|---|---|---|
| Rows of crow-foot braces | 2 | 3 |
| Number in 1st row | 4 | 5 |
| Length of braces in 1st row | 42 in. | 42 in. |
| Number in 2d row | 2 | 3 |
| Length of braces in 2d row | 48 in. | 48 in. |
| Number in 3d row | | 2 |
| Length of braces in 3d row | | 60 in. |
| Distance from shell to 1st row | 6 in. | 6 in. |
| Distance between rows | 5 in. | 5 in. |
| Least area of brace in weakest part (solid braces). | 0.8 sq. in. | 0.8 sq. in. |
| Least diameter of rivets | $1\frac{5}{16}$ in. | $1\frac{5}{16}$ in |

per square inch to find the total load. This divided by the "working strength" of the type of brace to be used will give the number required. These should be arranged in the general manner shown in Fig. 29, and the distance between the rivets checked

by the values given in Table XXIII. If $p$ is found to be too great, more braces should be added. Crow-foot braces are

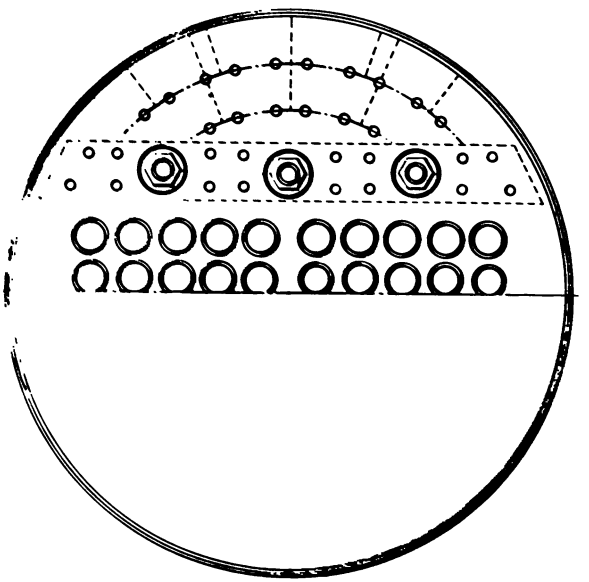


Fig. 30. Arrangement for Combined Through and Diagonal Bracing.

TABLE XXVI.

DATA FOR COMBINED THROUGH AND DIAGONAL BRACING.

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...ed to low pressures and to boilers of moderate diame-
... through bracing is better for the larger sizes when

high pressures are to be carried. Fig. 29 shows the general arrangement for crow-foot bracing, and Table XXV. gives data and dimensions for boilers 42 and 48 inches in diameter, braced in this way for a working pressure of 100 pounds, with a factor of safety of 6.

A good arrangement for boilers 54 and 60 inches in diameter is a combination of "through" and "diagonal" bracing, using the

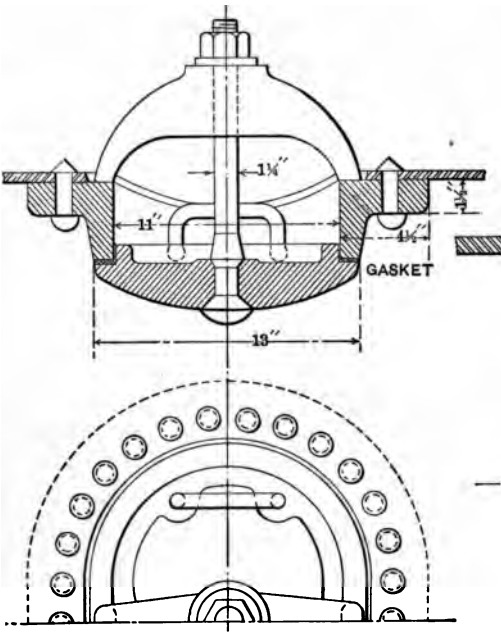


Fig. 31. Cast-Iron Manhole Ring and Cover.

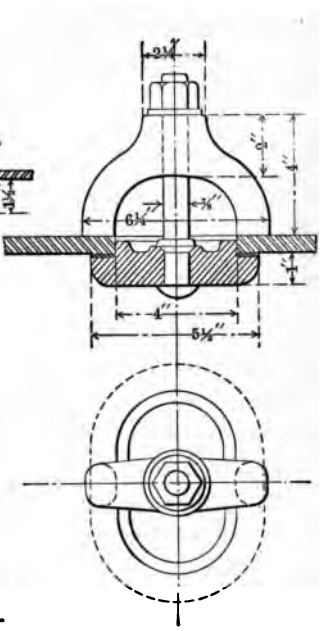


Fig. 32. Handhole Cover.

lower channel and through braces as shown in Fig. 30 and replacing the upper channel and through braces with those of the solid crow-foot type. This arrangement makes it much easier to enter a boiler for inspection, which is difficult if not impossible when complete through bracing is used in boilers of small size. Table XXVI. gives data for the combination bracing of boilers 54 and 60 inches in diameter, for a working pressure of 100 pounds per square inch, with a factor of safety of 6.

*Low Pressure Boiler.*—In designing a boiler for low-pressure heating it is good practice to give it sufficient strength to safely carry 100 pounds pressure; this allows a large factor of safety and makes ample provision for the effects of corrosion and adds to the life of the boiler.

### Nozzles, Brackets, Feed Pipes, Etc.

*Manhole.*—Access to the interior of a boiler is provided for by a manhole; this is usually located in the shell on top of the boiler, and must be large enough for a man to pass through easily. The

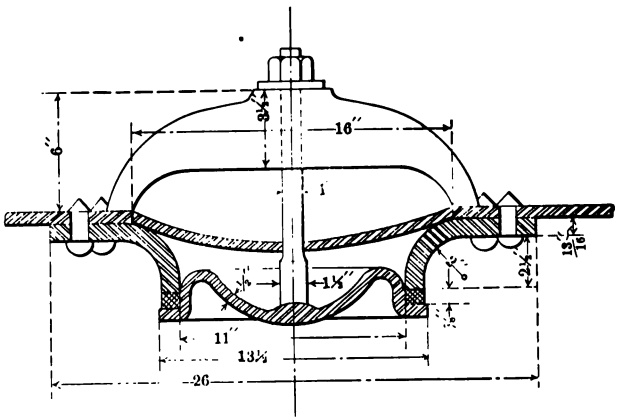


Fig. 33. Steel Manhole Ring and Cover.

opening is oval in form and commonly 11 by 15 inches in size. Sometimes the manhole is placed in the front head of a boiler below the tubes. If this is done additional stays must be provided to take the place of the tubes which are necessarily omitted.

Fig. 31 shows a common form of cast-iron manhole cover and frame, designed to carry a pressure of 150 pounds per square inch. Fig. 33 shows a section through a forged iron or steel manhole, designed for the same pressure.

*Handholes.*—These are placed in the lower part of each head for use when washing out the boiler. Fig. 32 shows a common form, consisting of a gun iron or cast steel cover and yoke. A gasket is provided for making a tight joint the same as in the

case of a manhole. The bearing surface should be at least ¾ inch wide for a handhole and 1 inch for the manhole.

*Nozzles.*—These are made of the same material as the manhole, either gun iron or cast steel. They are usually of the same diameter throughout, but for power work it is better to taper them, making the end connecting with the boiler somewhat larger than the size called for. This form presents less resistance to the flow of steam than when the diameter is made uniform.

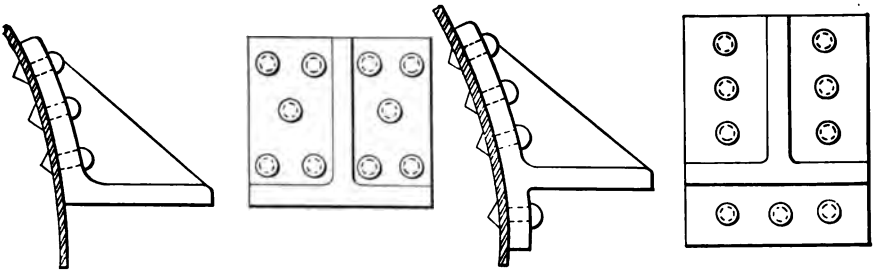

Fig. 34. Fig. 35.

Supporting Brackets.

*Brackets.*—Horizontal tubular boilers are usually supported by cast-iron brackets riveted to the shell and resting upon the brickwork of the setting. The brackets are so placed that their bearing surfaces are 3 or 4 inches above the center line of the boiler. Boilers up to 17 feet in length are provided with two pairs of brackets, while those of greater length have a third pair located midway between the others. Care should be taken to locate the brackets so that the load shall be evenly distributed among the entire number. Figs. 34 and 35 show the usual forms of brackets now in use. The former is the more common, while the latter has the advantage of greater strength.

Boiler makers have standard patterns for manholes, nozzles, brackets, etc., which they use with boilers of different sizes; so in specifying, it is usually best to rely upon forms and sizes which their experience has found to be satisfactory, rather than to prepare special patterns. The examples given here will be found useful for comparison and also an assistance in the design of special forms.

*Feed Pipe.*—The feed pipe should be of brass, except that portion exposed to the hot gases in the extension front, which should be of extra heavy wrought iron. The pipe usually enters the front head just above the tubes at one side and is carried to a point about 2 feet from the rear head, then across, and ends in an elbow looking down between the tubes and the shell. Sometimes the end is plugged and small holes are drilled in the sides of the pipe. The object in any case is to deliver the water in the coolest part of the boiler, and in such a manner as to prevent its being discharged in any amount against the hot plates.

## CHAPTER VI.

### BOILER FURNACES.

The requirements of a good furnace are: first, ample capacity, both as regards grate surface, and space for combustion; second, grates of such form that ashes and clinkers may be easily and quickly removed; third, the construction should be such that the gases may be completely burned before coming in contact with the comparatively cool surfaces of the boiler shell and tubes; fourth, thick or hollow walls should be provided to prevent the loss of heat by radiation. The furnace will necessarily vary in shape and size with the type of boiler and the kind of fuel to be used. With anthracite coal the grates may be placed about 24 inches from the boiler shell, but if bituminous coal is to be used this distance should be from 30 to 36 inches for the average grades and preferably more for fatty or gaseous coals. There should be a uniform and ample supply of air to the ash pit, and in the case of smoky fuels, provision should be made for admitting a small quantity of air above the fire for a short time after firing fresh coal.

#### Grates.

*Proportions.*—Grates should not be larger than can be conveniently fired and cleaned. A hand-fired grate should not in general be over 6 feet in length, and if over 4 feet in width, two firing doors should be provided. The grates are usually inclined from ¾ to 1 inch per foot in length toward the rear, to aid in firing.

The form of grate bars and the amount of air space depend upon the fuel to be used. For fine sizes of anthracite the air spaces should be as small as can be used without choking the draft, and are often made as small as ¼ inch or even less. For large sizes of anthracite and for bituminous or coking coal the spaces are sometimes increased to 1 inch. In general, the free area through the grate varies from 30 to 50 per cent of the total area.

*Plain or Stationary Grates.*—These are usually made up in sections of from one to three bars and should not be over 3 feet in length. They should be thinner at the bottom than at the top, as indicated in Fig. 36, which shows a section through the ordinary parallel bar.

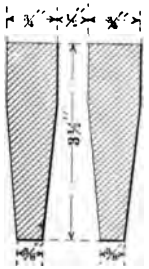

Fig. 36.

The "herring bone" grate bar, Fig. 37, is another form in common use. In plants of small size, and especially those burning anthracite coal of egg size and larger, the plain grate is probably as satisfactory as any.

*Shaking Grates.*—For coals which are high in ash, and which tend to form clinker, certain forms of the shaking or rocking grate are preferable. There are many forms of these grates, by means of which the clinker can be broken up without opening the furnace doors. The advantages claimed for shaking grates are: ease of operation, the avoidance of admitting cold air to the furnace through open doors, and the thoroughness with which the clinker may be broken up and the ashes removed

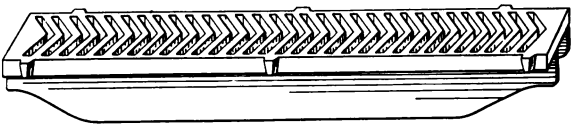

Fig. 37. Herring Bone Grate Bar.

from the fire. To be effective, the construction should be such that the moving parts will not clog, and the clinker will be thoroughly and easily broken up by their action.

Grates of this kind may be divided into three general classes: the shaking or rocking grate, the dumping grate, and the combined shaking and dumping grate. The Foster grate with part of its bars removed is shown in Fig. 38. This is a typical shaking grate, and is made up of flat bars supported at each end upon cross pieces which in turn rest upon the side bars of the frame. There are two cross supports or "rocking bars" at each end, and alternate grate bars rest upon these two sets of supports. The

grate has a direct lateral or sliding movement and is so fitted that there is no lost motion. One of the shakers operates one

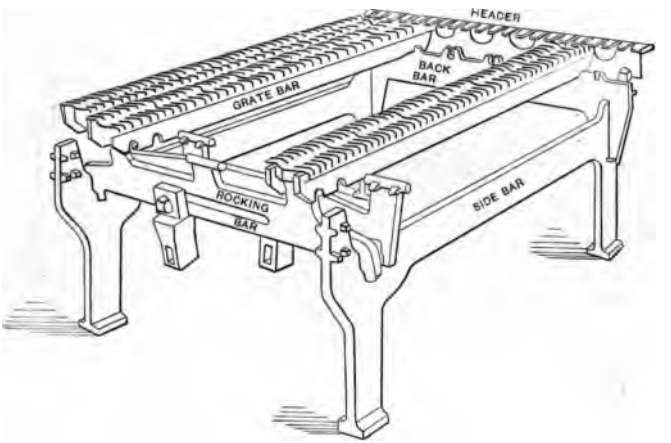


**Fig. 38. Foster Shaking Grate.**

half of the bars and the other the remainder. The grate presents a level surface at all times as shown in the cut.

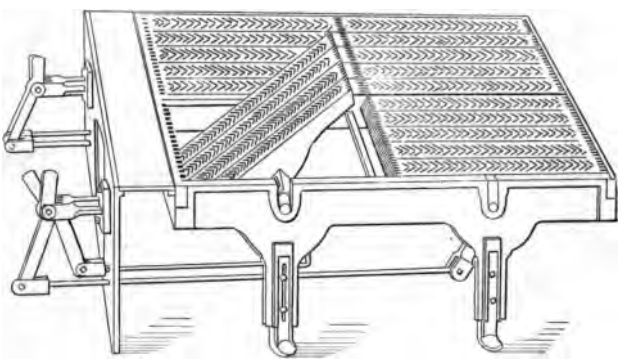

**Fig. 39. Salamander Dumping Grate.**

In the dumping grate the sections are made larger, and when the fires are to be cleaned from clinker a section is rocked from

a horizontal to a vertical position, thus breaking up the clinker and allowing it to fall through the large opening thus made, into the ash pit. The Salamander grate, Fig. 39, illustrates this type.

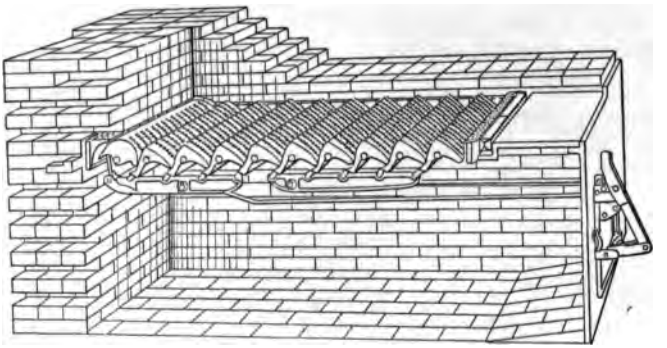

Fig. 40. McClave Rocking and Dumping Grate.

The McClave rocking and dumping grate, Figs. 40 and 41, illustrates the third type. Fig. 40 shows the rocking motion which is used to break up a soft coal fire when it cakes, or to

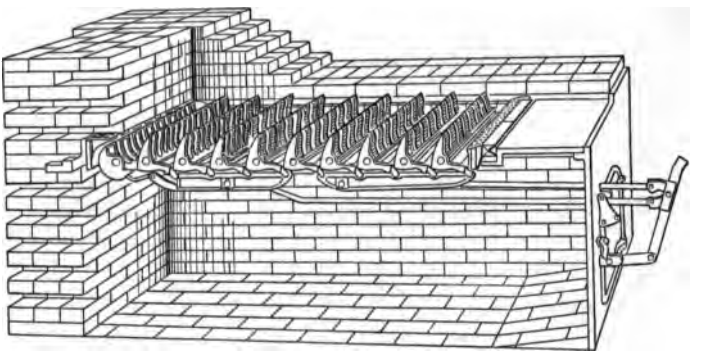

Fig. 41. McClave Grate.

remove the fine ashes from a hard coal fire when there is but little clinker formed. The cut-off movement in Fig. 41 is for breaking up large clinkers and dumping them into the ash pit.

The grates are divided into two parts so that each may be operated independently of the other.

Fig. 42 shows the White hollow-blast rocking grate. This is designed especially for burning refuse and low-grade fuel. The furnace is so constructed that the air from the blower passes into the bridge-wall duct, then by means of hollow trunnions into

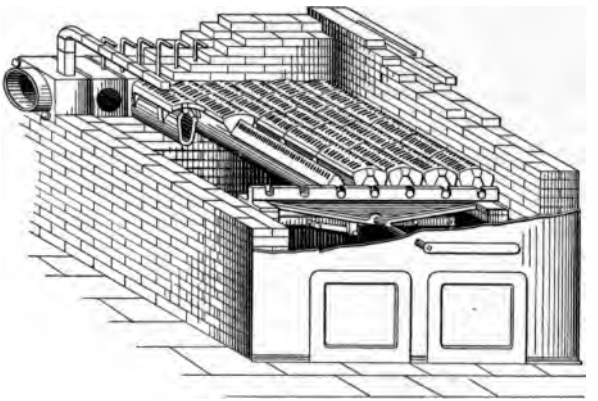

**Fig. 42. White Hollow Blast Grate.**

air chambers running the full length of each grate bar, from which it passes upward in finely divided streams through the tops of the bars. The advantage claimed for this is the uniform distribution of the air over the entire surface of the grate and its thorough mixture with the gases of combustion. This type of grate is also made for a natural draft.

*Loss Through Shaking Grates.*—There is a certain amount of loss from unburned coal which falls through into the ash pit when shaking grates are used. This usually amounts to from 1 to 3 per cent of the total coal consumed, even with the most careful handling, but is more than offset by the improved combustion due to the greater freedom from ash and clinker.

### Mechanical Stokers.

In large plants where it is desirable to reduce the labor of firing, mechanical stokers are used. With a good form of stoker one man can care for several furnaces. Other advantages are

more even firing, better combustion, and the introduction of coal with closed furnace doors. When properly designed these stokers feed both coal and air at a regular rate, and may be so adjusted that when the coal is burned in a suitably constructed furnace, combustion of the gases will take place with the production of but little, if any, smoke. The chief objection to mechanical stokers is their first cost, but in plants of large size this is usually more than offset by increased efficiency and a reduction in the cost of firing.

*Over-fed Stokers*—Stokers are of two general types, known as "over fed" and "under fed." The Roney stoker, Fig. 43, illustrates one of the former. Fuel is fed into the hopper from which

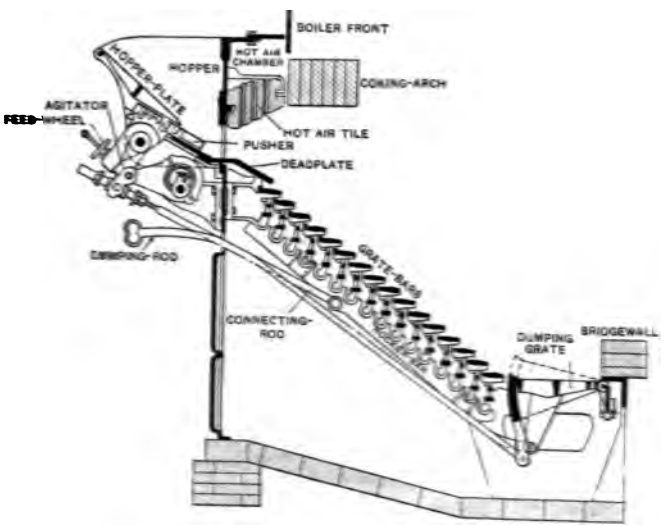


Fig. 43. Roney "Over-fed" Stoker.

it is gradually forced by the pusher over the dead plate, onto the grates, which form a series of steps descending to the dumping grate near the bridge wall as shown. The grate bars are coupled together by a rocker bar which is given a backward-and-forward motion, thus causing the fuel to slide forward a short distance at each stroke. The rate of feeding is controlled by the length of

the stroke of the pusher, or by changing the number of strokes per minute. All ashes and cinders are deposited on the dumping grate near the bridge wall. These stokers are usually operated by a small independent steam engine placed at one side of the boiler setting.

The Acme and Wilkinson stokers are somewhat similar to the one just described, both having the inclined grates with movable bars giving a forward movement to the coal which is fed into a hopper in front. The peculiar feature of the Wilkinson stoker is the use of hollow grate bars through which air is forced by means of small steam jets.

Another form of the over-fed type is the Duluth stoker shown in Fig. 44. The grate bars in this case are carried by endless chains which run over sheaves at the rear of the furnace and

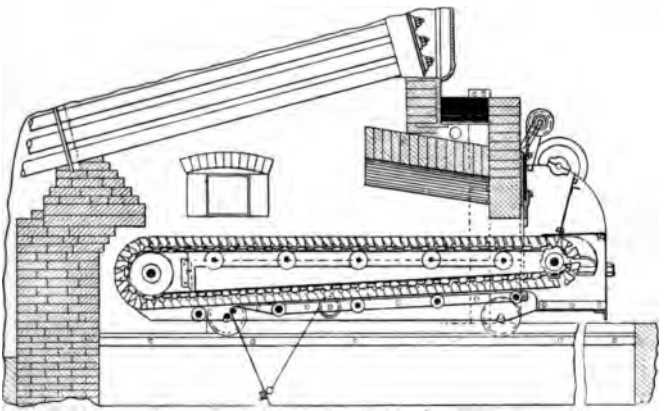

**Fig. 44. Duluth Chain Grate Stoker.**

sprockets in front, from which they receive their motion. The coal is fed into a hopper in front and is regulated by an adjustable distributing plate which extends across the grate at a height above it to give the desired thickness of fire. The stoker is mounted on trucks and can be easily drawn out of the furnace for inspection and repairs.

Other chain-grate stokers are the Babcock and Wilcox, the Playford Chain Grate stoker, the Coxe Automatic stoker and

the Green Traveling Link stoker. There are a number of other over-fed stokers of different forms but operating on the same general principles as those already described.

*Under-fed Stokers.*—The American stoker, Figs. 45 and 46, is of the under-fed type, and requires a forced draft for its operation. Just below the coal hopper, and connecting with it, is the conveyor pipe which in turn connects with the coal magazine. A screw conveyor or worm is located in the conveyor pipe and extends the entire length of the magazine. Air under pressure is brought into

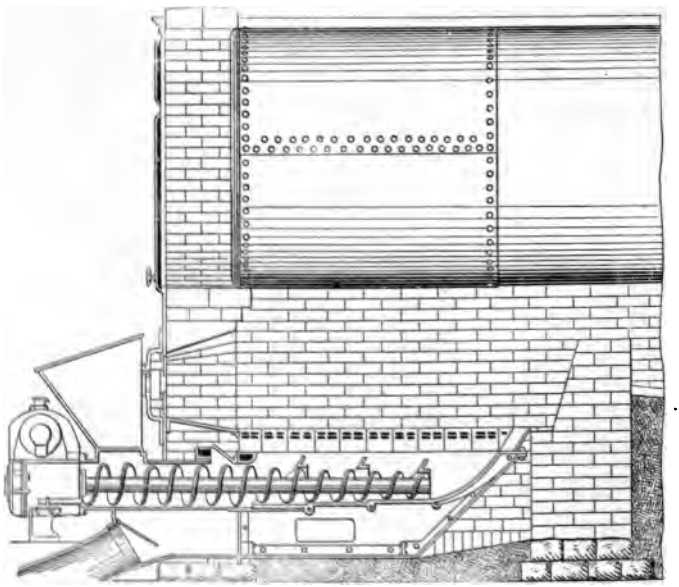

Fig. 45. American Under-fed Stoker.

the space between the magazine and the outer casing and is discharged through openings in the air blocks around the upper edge of the magazine. This is shown more plainly in Fig. 46, which represents a cross section through the furnace. Each stoker is driven independently by a small steam motor located in front and beneath the hopper.

The Jones stoker, Fig. 47, is another of the same type. This has a plunger in place of the worm, the plunger being operated

by a steam piston which may be worked automatically or by hand. This stoker requires a forced draft similar to the one just described. The Taylor stoker is another of the under-fed type.

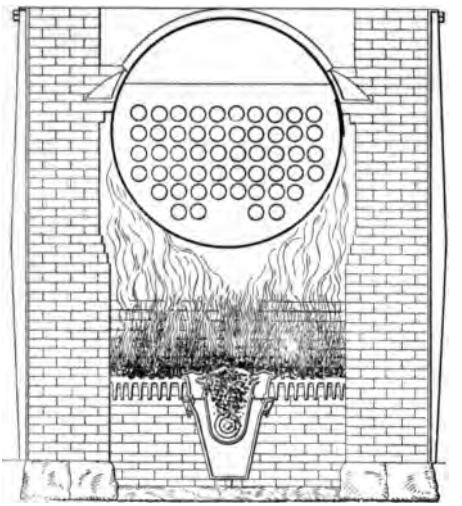

**Fig. 46. Cross Section of American Stoker.**

### Special Furnaces.

The furnaces illustrated thus far have been of the usual form except for such slight changes as are necessary to adapt them

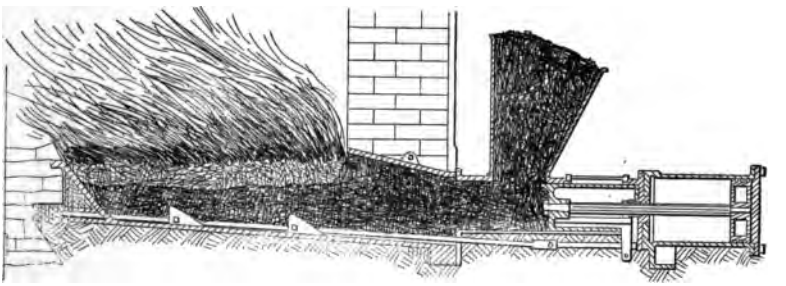

**Fig. 47. Jones Under-fed Stoker.**

to the various grates and stokers which have been described. We will now show two or three forms of special furnaces designed

with particular reference to the complete combustion of the gases and the prevention of smoke.

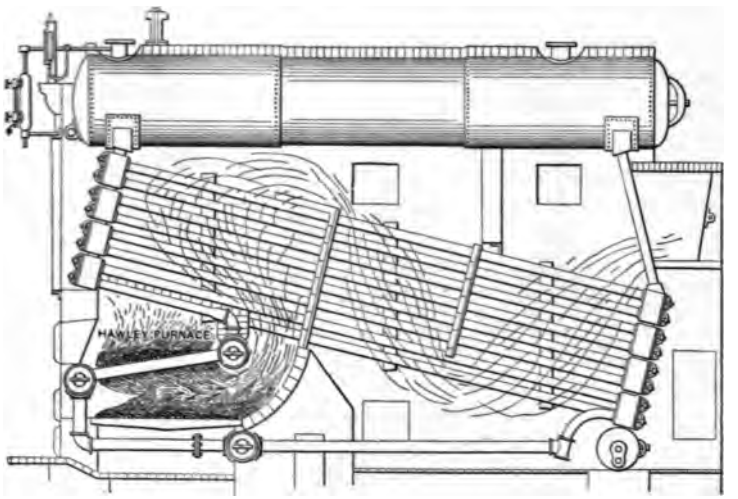


**Fig. 48. Hawley Down-Draft Furnace.**

*Hawley Down-Draft Furnace.*—In this furnace there are two grates about a foot apart as in Fig. 48. The coal is fed upon the

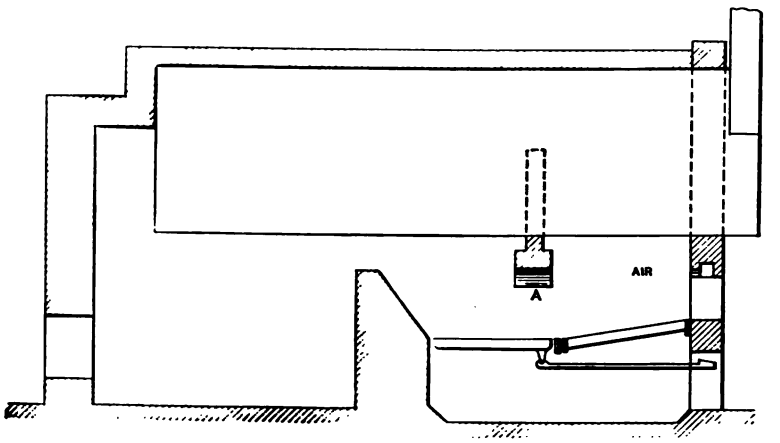


**Fig. 49. Walker Furnace for Soft Coal.**

upper grate and as it becomes partly consumed, it falls through to the grate below where the combustion is completed. The draft

is downward through the upper grate and upward through the lower, the gases being taken off from the space between them. The greater part of the air required for combustion is admitted through the fire door of the upper grate.

The upper grate in this furnace is made up of water tubes connected with the boiler, through which the water circulates. It is claimed that with this arrangement of grates the combustion is very complete and the amount of smoke produced correspondingly small.

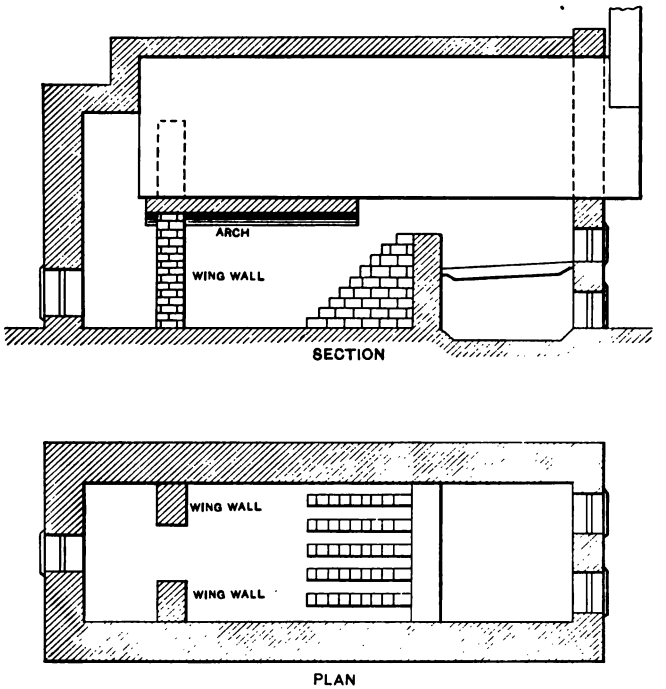


**Fig. 50. Wing Wall Furnace.**

*Walker Furnace.**—This is designed especially for burning soft coal. The grate is in two parts, the forward part being stationary and sloping toward the dumping grate at the rear, as in Fig. 49. A fire-brick arch *A*, with a vertical wall above it is built across the center of the furnace over the rear grate. Fresh fuel is fired upon the front part of the grate, and after the

gases have been given off it is pushed back upon the dumping grate. Air is admitted through both grates from the ash pit and also above the fire through an opening in the front wall over the furnace door. The arch *A* serves to deflect the mixture of air and gases downward toward the incandescent coke upon the dumping grate which insures complete and smokeless combustion, if proper care is used in firing.

*The Wing Wall Furnace.**—This furnace as applied to a horizontal tubular boiler is shown in Fig. 50, and differs from the ordinary form of furnace by having two vertical walls, with a narrow opening between them, built back of the bridge wall near the end of the boiler. In addition to these, there is a fire-brick arch over the combustion chamber and a series of short walls or piers back of the bridge wall. Coal is fired alternately upon one half of the grate at a time and the smoky gases from the freshly fired side and the excess of very hot air passing through the bed of bright coal on the other side are brought together by passing through the narrow opening between the wing walls, and combustion is therefore made much more complete. The fire-brick piers back of the bridge wall absorb a large amount of heat from the fire when it is hottest and give it out again to the cooler gases which pass into the combustion chamber after fresh coal has been fired.

*From *Steam Boilers*, by William Kent

## CHAPTER VII.

### BOILER SETTINGS.

*Foundations.*—The first requirement of a good boiler setting is a substantial foundation. Where the soil is firm this may be either of concrete or rough stone laid in cement. The width of the foundation walls should be at least 16 inches wider than the walls of the setting which they support, thus allowing 8 inches upon each side. In the case of heavy settings for power work the foundation may be made from 20 to 24 inches wider than the brickwork, and in some cases a solid bed of concrete large enough to support the entire setting is provided. The depth of the foundation is usually made from 20 to 24 inches for boilers up to 48 inches in diameter and from 24 to 30 inches for larger sizes. These dimensions apply only where a solid earth footing is available, much heavier foundations being required if the earth is soft or yielding. Good concrete is obtained by using one part Portland cement, two parts sand, and four parts broken stone, the pieces of which should not be over 2 inches through. Concrete should be put down in layers not over 6 inches in thickness, each layer being thoroughly rammed before the next one is laid.

Foundations of this kind should be surrounded with board forms to hold the concrete while it is being laid. For the best results a Portland cement concrete foundation should be allowed to stand two months before loading. The time may be shortened somewhat, if necessary, provided the foundation is suitably proportioned and carefully watched, especially if the concrete is made as dry as possible.

*Brickwork.*—The setting above the foundation should be of hard-burned brick laid in freshly-made cement mortar made of one part Portland cement to two parts of clean, sharp sand. The furnace, bridge wall, and arching over the rear connection or combustion chamber should be lined with fire brick laid in pure cement or a mixture of fire clay and ground fire brick, with very close joints.

In setting boilers for power work it is customary to line the entire space exposed to the fire and hot gases with fire brick, and this is often done in the case of heating boilers in plants of considerable size. The outer walls, both at the sides and rear, should be made double with an air space between to reduce the conduction of heat through the walls.

*Arch Bars.*—One part of the setting which requires especial care is the construction of the arch over the back connection, where the setting closes up against the back head of the boiler. This is sometimes turned from the back wall forward, as in Fig.

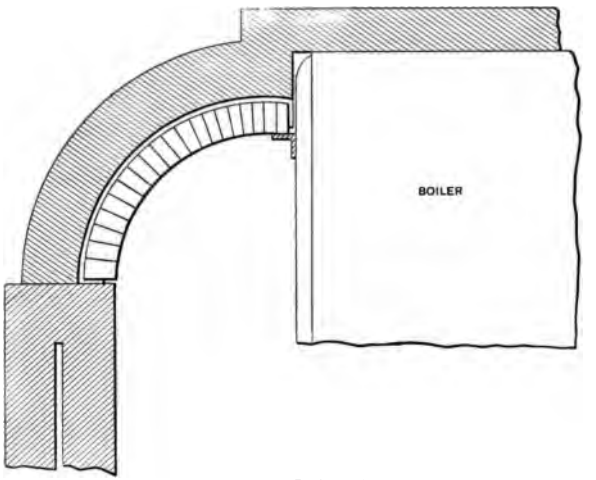


Fig. 51. Boiler Arch.

51. An angle iron is either riveted to the boiler head or supported in the side walls of the setting for the front of the arch to rest upon. The fire-brick lining is held in position by cast-iron arch bars and the whole construction covered over with brickwork. A space of at least an inch should be left between the arch and the end of the boiler to allow for expansion. One objection to this form of arch is the exposed position of the angle iron support, which is liable to be injured from contact with the hot gases which pass over it.

The effects of expansion and contraction of the boiler and setting are more apt to weaken the arch when made in this

manner than when it is sprung from the side walls. In this case the arch is supported by bars so designed that a very limited part of the metal is exposed to the direct heat of the furnace gases. The form of bar used in the standard "Hartford Setting" is shown in Fig. 52. It consists of a curved piece of the dimensions shown, cast to a radius of 8 feet. The bricks are laid up against

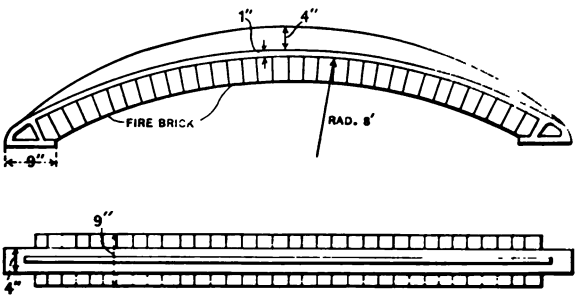


Fig. 52. Arch Bar.

the bar in an arch as shown, and are held in position at either end by projections cast upon the bar. In Fig. 53 the arches are shown in position. Three of these, arranged side by side, are in

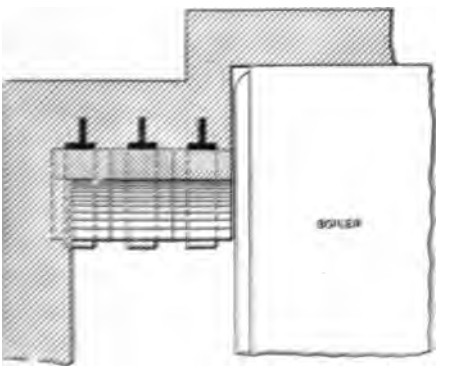

Fig. 53. Arch Sprung from Side Walls.

most cases sufficient to cover the space between the boiler and the rear wall. The ends of the iron supporting bars rest upon the side walls of the setting, and the rear wall is built up around the arch as shown.

Before placing the fire brick in the arch bar it should be

turned bottom upward. If "arch brick" curved to an 8-foot radius can be had they should be used; if not, common fire brick will answer the purpose, but in this case every third or fourth brick should be beveled so that no large spaces will be left between them when they are in position. The last brick to be put in is the key brick in the center of the arch, which must necessarily be driven in endwise.

After the bricks have been carefully fitted in position, they should be removed, then wet and coated with a thin paste of fire clay and water, and put in place in the bar. The bar with the bricks in position, should next be turned right side up, and the spaces between them filled with a paste made of fire clay, ground fire brick and water. After the whole has dried and hardened, the arch may be placed in position upon the setting.

*Covering.*—The top of the boiler is protected in some cases by springing a brick arch over it, leaving an air space of an inch or two between the brickwork and the shell, but more commonly light burned brick are placed loosely upon the side over the boiler shell, these in turn being covered with a layer of hard brick laid in cement mortar.

*Iron Work.*—From three to five pairs of buck stays with tie rods, depending upon the length of the boiler, should be provided to prevent the outer walls from spreading. Heavy cast iron plates about 20 inches in length, and planed upon the upper surface should be placed upon the side walls for the lugs or brackets to rest upon, and three iron rolls about 1 inch in diameter should be provided beneath each bracket, except the front ones, for carrying the boiler during expansion and contraction. Special care should be taken to leave a clear space back of each movable bracket to allow freedom of expansion without bringing excessive strains upon the brickwork. The boiler front is made of cast iron, and provided with doors for access to the tubes, furnace, and ash pit.

### Dimensions of Boiler Settings.

Table XXVII. gives common dimensions for both light and heavy settings, and is to be used in connection with Figs. 54, 55, and 56.

# TABLE XXVII.

## DIMENSIONS FOR BOILER SETTINGS.

| | Heavy setting for power. | | | | | | | | Light setting for heating. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dia., inches. | 30 | 36 | 42 | 48 | 54 | 60 | 66 | 72 | 30 | 36 | 42 | 48 | 54 | 60 | 66 | 72 |
| A | 22 | 26 | 26 | 26 | 30 | 30 | 30 | 30 | 22 | 22 | 22 | 22 | 22 | 22 | 26 | 26 |
| B | 8 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| C | 12 | 12 | 12 | 12 | 16 | 16 | 16 | 16 | 12 | 12 | 12 | 12 | 12 | 12 | 16 | 16 |
| D | 7 | 7 | 7 | 7 | 11 | 11 | 11 | 11 | 7 | 7 | 7 | 7 | 7 | 7 | 11 | 11 |
| E | 8 | 8 | 8 | 12 | 12 | 12 | 12 | 12 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| F | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 8 | 8 | 8 | 12 | 12 | 12 | 12 | 12 |
| G | 8 | 8 | 8 | 12 | 12 | 12 | 12 | 12 | 8 | 8 | 8 | 12 | 12 | 12 | 12 | 12 |
| H | 22 | 22 | 22 | 26 | 26 | 26 | 26 | 26 | 18 | 18 | 18 | 22 | 22 | 22 | 22 | 22 |
| I | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 20 | 20 | 20 | 24 | 24 | 24 | 24 | 24 |
| J | 8 | 8 | 8 | 8 | 9 | 9 | 10 | 10 | 8 | 8 | 8 | 8 | 9 | 9 | 10 | 10 |
| K | 24 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 24 | 26 | 26 | 26 | 26 | 26 | 26 | 26 |
| L | 24 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 24 | 26 | 26 | 26 | 26 | 26 | 26 | 26 |
| M | 20 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 20 | 20 | 20 | 22 | 22 | 22 | 22 | 22 |
| N | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| O | 22 | 22 | 22 | 24 | 24 | 24 | 24 | 24 | 22 | 22 | 24 | 24 | 24 | 24 | 24 | 24 |
| P | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 |
| Q | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 |
| R | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
| S | 2-10 | 3 4 | 3 10 | 4-4 | 4-10 | 5-4 | 5-10 | 6-4 | 2-10 | 3-4 | 3-10 | 4 4 | 4-10 | 5-4 | 5-10 | 6-4 |
| T | 4-0 | 4-10 | 5 4 | 5-10 | 6-8 | 7-2 | 7-8 | 8-2 | 4-0 | 4-8 | 5-2 | 5-8 | 6-4 | 6-10 | 7-10<br>7-4 | 8-4<br>7-10 |
| Length of setting = Length of tubes + | 3-6 | 3-8 | 3-8 | 4-2 | 4-2 | 4-2 | 4-2 | 4-2 | 3-2 | 3-4 | 3-4 | 3-10 | 3-10 | 3-10 | 3-10 | 3-10 |
| Width of setting, 1 boiler | 5-8 | 6-10 | 7-4 | 7-10 | 9-6 | 9-6 | 10-0 | 10-6 | 5-8 | 6-2 | 6-8 | 7-2 | 7-8 | 8-2 | 9 10<br>9-4 | 11-4<br>9 10 |
| Width of setting, 2 boilers | 9-8 | 11-8 | 12-8 | 13-8 | 15-8 | 16 8 | 17 8 | 18 8 | 9-8 | 10 10 | 11-10 | 12-10 | 14-0 | 15-0 | 17 8<br>16 8 | 18-8<br>17-8 |
| Width of setting, 3 boilers | 13-8 | 16-6 | 18-0 | 19-6 | 22-4 | 23-10 | 25-4 | 26-10 | 13-8 | 15-6 | 17-0 | 18-6 | 20-4 | 21-10 | 25-6<br>24-0 | 26-6<br>25-0 |
| Width of setting, 4 boilers | 17-8 | 22-4 | 23-4 | 25-4 | 29-0 | 31-0 | 33-0 | 35-0 | 17-8 | 20-2 | 22-2 | 24-2 | 26-8 | 28-8 | 33-4<br>31-4 | 34-10<br>33-10 |

NOTE. — Upper figures at bottom of last two columns to be used when width of grate equals diameter of boiler.

The distance on centers between the boilers as given in the table is based on the assumption that the projection of the

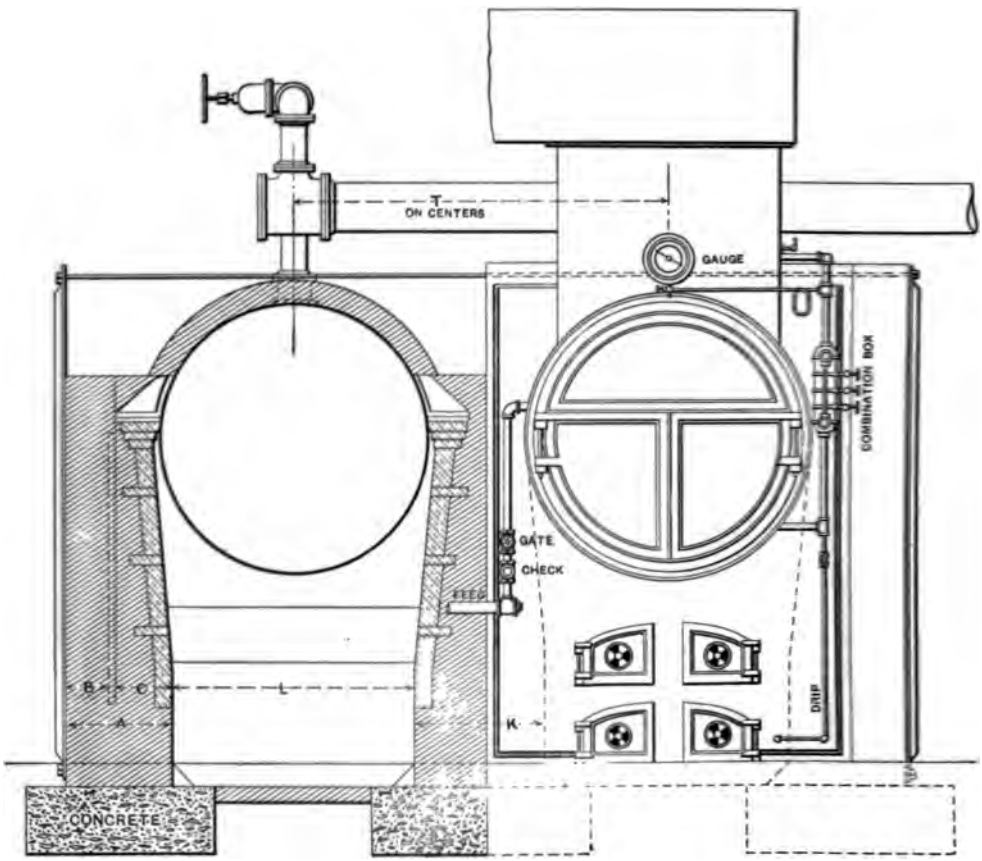


**Fig. 54. Cross Section and Front Elevation of Boiler Setting.**

brackets from the boiler shell shall not exceed the figures given below.

| Diameter of boiler, inches | Maximum projection of brackets, inches |
|---|---|
| 42 | 9 |
| 48 | 9 |
| 54 | 10 |
| 60 | 10 |
| 66 | 12 |
| 72 | 12 |

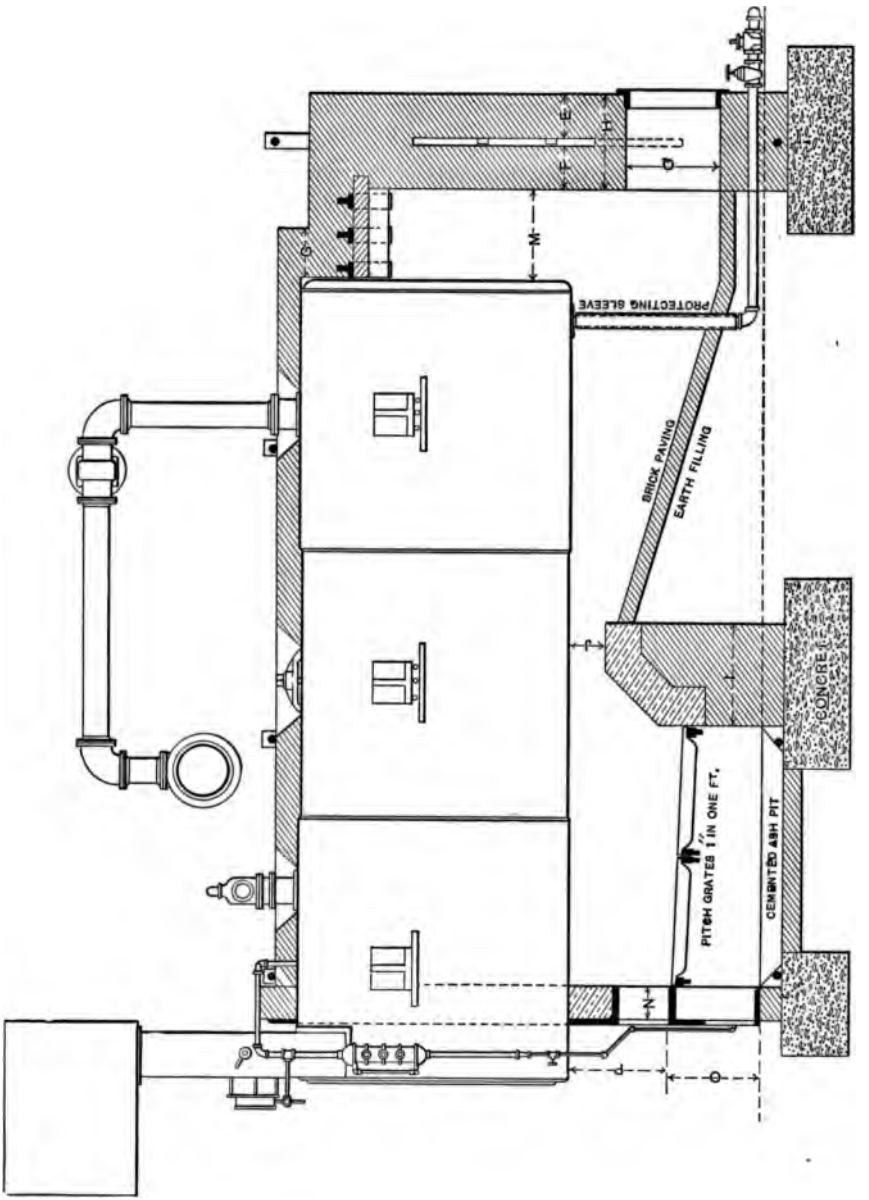


**Fig. 55. Longitudinal Section of Boiler Setting.**

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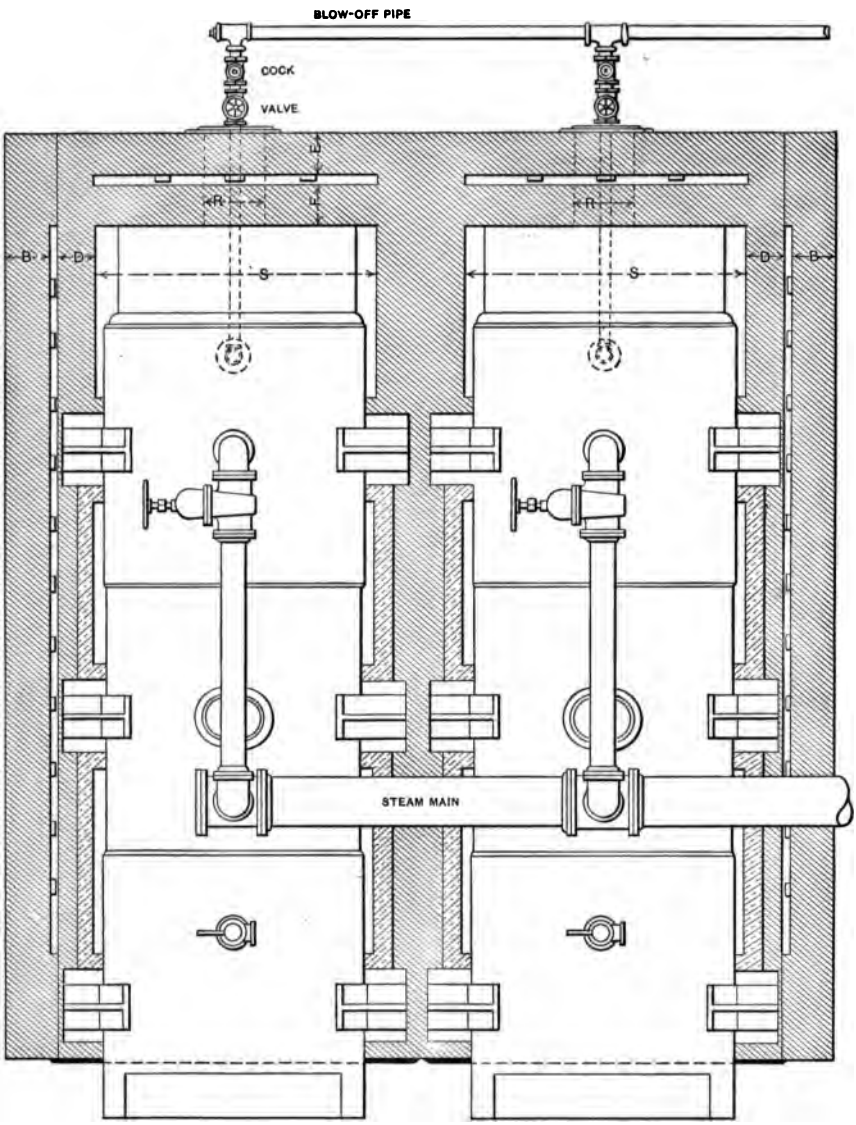



Fig. 56. Horizontal Section of Boiler Setting.

If the projection is greater than given here, the thickness of the division wall must be increased accordingly.

**Data for Design of Boiler Supports.**

*Gallows-Frame Supports.*—A form of support for tubular boilers which is coming into quite common use is the metal gallows frame. Boilers supported in this manner are entirely

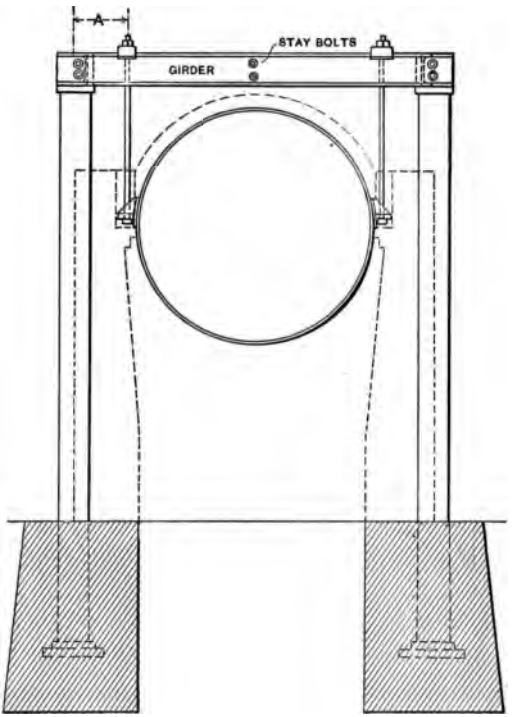



**Fig. 57. Gallows Frame Support—End View.**

independent of the brickwork, and when properly erected, expansion may take place without injury to the walls, which gives it a decided advantage over the common form of setting. There are several ways of constructing a support of this kind depending more or less upon the taste and skill of the designer. A very satisfactory arrangement, and one that is comparatively easy to

construct, is shown in Figs. 57 and 58, which represent the end and side views respectively of a boiler supported in this manner.

The four columns are of wrought-iron pipe provided with flanges at the lower end and embedded from one fourth to one third of their length in concrete foundations.

The girders are made up of two channels placed back to back about 2 inches apart. A cast-iron cap having a tubular extension is placed on the top of each column, which should be trued in a lathe, and is bolted in position. This cap has a flange, or stem, 2 inches thick extending to the top of the channel girders, which

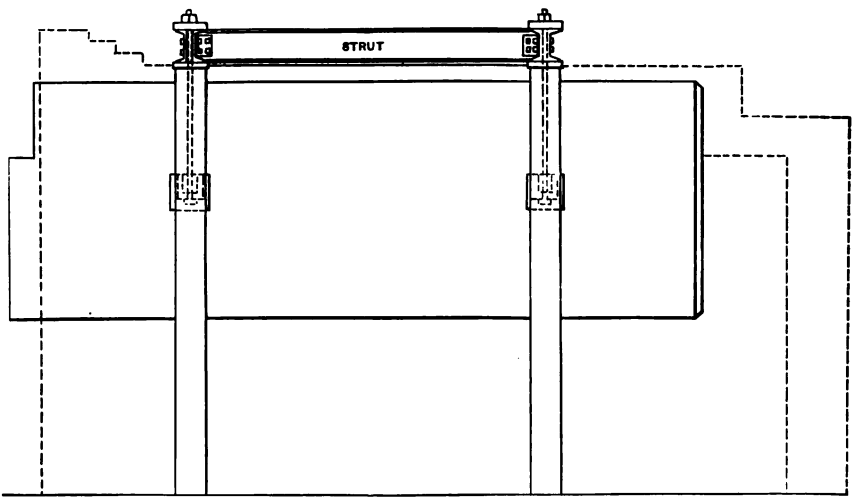



Fig. 58. Gallows Frame Support—Side View.

are bolted to it. The top or bearing surface should be beveled lengthwise of the girder from a point about an inch each side of the center as shown at *dd*, Fig. 59, in order that the load may always be applied at the center of the column. The suspension rods extend upward between the two channels and are provided with heavy nuts and washers at the ends. The washers distribute the load equally between the channels, and at the same time secure them against sidewise deflection by means of projections upon the under side, which are shown in Fig. 59. Two

of these projections fit over the edges of the flanges while the remaining one fits tightly between the channel webs as shown. The channels may be still further stiffened by bolting them at the center as indicated in Fig. 57. The connection between the sus-

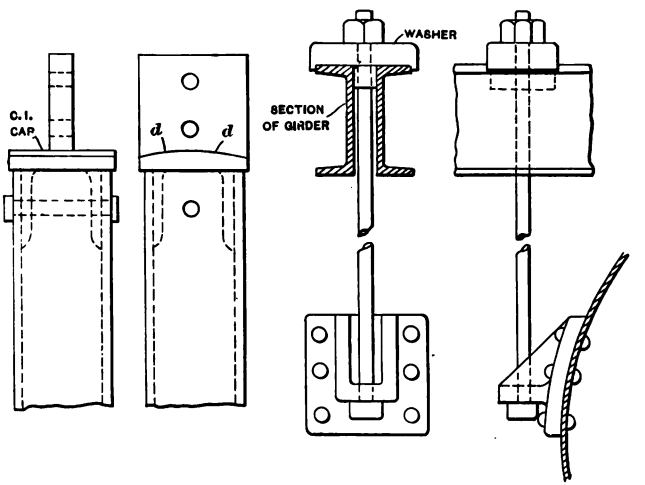



**Fig. 59. Details of Gallows Frame Support.**

pension rods and the boiler shell is made by means of a cast-iron lug as shown in Fig. 59. This is similar to the ordinary lug or bracket except the projection is made shorter to bring the rod as near to the shell as possible. Another method is to use wrought-iron hooks instead of lugs and attach them to loops at the ends of the suspension rods. In order to keep the front and rear girders the same distance apart and to still further strengthen the construction, it is well to put in two longitudinal struts, one over each side wall as shown in Fig. 58. Channels may be used for this purpose, fastened to the girders by means of angles and bolts.

When two boilers are set in a battery the gallows frame may be made as indicated in Fig. 60, or the support for the second boiler may be a duplicate of that already described for a single boiler, the inner ends of the girder resting upon the same column which passes up through an opening in the division wall.

The method shown in Fig. 60 is preferable on account of its simplicity, and the cost of the heavier girders and supports is usually less than that of the extra columns and foundations. The method of proportioning the various parts is as follows:—

*Suspension Rods.*—The weight of the boiler full of water together with the piping which it supports, divided by 4, gives the load on a single rod, and this divided by 10,000 (the safe working stress per square inch) will give the required sectional area for a steel rod.

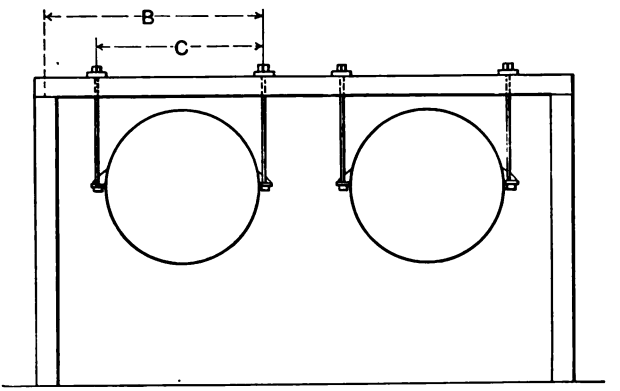



**Fig. 60. Support for Two Boilers.**

As the end of the rod has a thread cut on it, it should be upset to a larger diameter, in order that the sectional area at the bottom of the thread may be equal to, or greater, than that of the solid rod.

Table XXVIII. gives the necessary enlargement.

## TABLE XXVIII.

### DIMENSIONS OF SUSPENSION RODS.

| Diameter of rod. Inch. | End upset to Inch. | Number of threads per inch. |
|---|---|---|
| 1 | 1⅛ | 8 |
| 1⅛ | 1¼ | 8 |
| 1¼ | 1⅜ | 7 |
| 1⅜ | 1½ | 6 |
| 1½ | 1⅝ | 6 |
| 1⅝ | 1¾ | 5½ |
| 2 | 2⅛ | 4½ |

*Girders.*—To determine the size of girder for a single boiler, multiply the load in pounds, on a single column (¼ the weight of boiler, etc.) by the distance in inches from the center of the column to the adjacent suspension rod. (See *A*, Fig. 57.) This gives the bending moment, which, in turn, divided by 10,000 pounds for steel, gives a quantity known as the section modulus. Table XXIX. gives the section modulus for different sizes of chan-

TABLE XXIX.

WEIGHT AND SECTION MODULUS OF CHANNELS.

| Size of channel. Inch. | Weight per foot. Pounds. | Section Modulus. |
|---|---|---|
| 6 | 8 | 4.3 |
| 7 | 9¾ | 6.0 |
| 8 | 11½ | 8.1 |
| 9 | 13¼ | 10.5 |
| 10 | 15 | 13.4 |
| 10 | 20 | 15.7 |
| 12 | 20½ | 21.4 |
| 12 | 25 | 24.0 |
| 12 | 30 | 26.9 |
| 15 | 33 | 41.7 |
| 15 | 35 | 42.7 |

nel bars, from which the required size can be selected, after determining the section modulus as above described. It should be borne in mind, however, that the load is equally divided between the two channels so that the section modulus of each need be only one half that computed for the whole girder.

For double settings (see Fig. 60) the load on each suspension rod is the same as for a single boiler but the load on each column and girder is twice as great. To find the bending moment in this case, multiply the load on a single column (¼ the weight of two boilers) by the distance *B*, Fig. 60; then multiply the load on a single suspension rod (¼ the weight of one boiler) by the distance *C*, and subtract the second product from the first; the remainder is the bending moment sought. Having determined the bending moment, the required size of the girder channels is found as before.

*Columns.*—The diameter of the pipe columns may be taken the same as the depth of the channels. This makes them amply

strong for carrying the load and also gives a good appearance. Table XXX. has been computed by the methods just described for boilers of different sizes, for single and double settings. It

## TABLE XXX.

DIMENSIONS OF GALLOWS FRAME SUPPORTS.

| Diameter of boiler, inches | Length of tubes, inches | Diameter of suspension rods, inches | Diameter of threaded ends, inches | Single boiler. | | Battery of two boilers. | |
|---|---|---|---|---|---|---|---|
| | | | | Columns | Girders | Columns | Girders |
| 48 | 11 | 1 | 1⅜ | 6-in. pipe | Two 6-in. channels, 8 lb. | 10-in. pipe | Two 10-in. channels, 20 lb. |
| | 13 | 1 | 1⅜ | 6 " " | " 6 " " 8 " | 10 " " | " 10 " " 20 " |
| | 15 | 1 | 1⅜ | 6 " " | " 6 " " 8 " | 12 " " | " 12 " " 20½ " |
| 54 | 12 | 1 | 1⅜ | 6 " " | " 6 " " 8 " | 12 " " | " 12 " " 25 " |
| | 14 | 1⅛ | 1½ | 7 " " | " 7 " " 9¼ " | 12 " " | " 12 " " 25 " |
| | 16 | 1⅛ | 1½ | 7 " " | " 7 " " 9¼ " | 12 " " | " 12 " " 25 " |
| 60 | 13 | 1⅛ | 1½ | 7 " " | " 7 " " 9¼ " | 12 " " | " 15 " " 33 " |
| | 15 | 1⅛ | 1½ | 7 " " | " 7 " " 9¼ " | 15 " " | " 15 " " 33 " |
| | 17 | 1⅛ | 1½ | 8 " " | " 8 " " 11¼ " | 15 " " | " 15 " " 33 " |
| 66 | 14 | 1⅛ | 1½ | 8 " " | " 9 " " 11¼ " | 15 " " | " 15 " " 33 " |
| | 16 | 1⅛ | 1½ | 8 " " | " 8 " " 11¼ " | 15 " " | " 15 " " 35 " |
| | 18 | 1¼ | 2 | 9 " " | " 9 " " 13¼ " | 15 " " | " 15 " I-beams 42 " |
| 72 | 16 | 1¼ | 2 | 9 " " | " 9 " " 13¼ " | 15 " " | " 15 " " 42 " |
| | 18 | 1¼ | 2 | 9 " " | " 9 " " 13¼ " | 15 " " | " 15 " " 45 " |
| | 20 | 1¼ | 2¼ | 10 " " | " 10 " " 15 " | 15 " " | " 15 " " 55 " |

will be noticed that for the larger sizes in the double setting, I-beams have been used in place of channels; this is on account of their greater strength for a given depth.

## TABLE XXXI.

DIMENSIONS OF PIERS FOR COLUMNS.

| Diameter of boiler. | One boiler, Size of piers. | Two boilers, Size of piers. |
|---|---|---|
| In. | In. | In. |
| 48 | 18x20 | 24x24 |
| 54 | 18x24 | 24x30 |
| 60 | 24x24 | 24x36 |
| 66 | 24x30 | 32x36 |
| 72 | 24x36 | 36x40 |

*Masonry.*—The walls in this type of setting may be lighter than in ordinary construction where they have to support the weight of the boiler. Two 8-inch walls, with a 2-inch air space between them

will usually be sufficient. The foundations may also be shallower, from 12 to 16 inches being sufficient where there is a good earth footing. The piers supporting the columns should extend from 16 to 24 inches below the bottom of the columns. For a solid earth footing of well-packed gravel the dimensions of the piers may be as given in Table XXXI.

Mr. George B. Francis gives the following permissible loads per square foot for different kinds of soil which will be found useful in designing the foundations for chimneys, boilers, engines, etc.: Hardpan, 8 tons; gravel, 5 tons; clean sand, 4 tons; dry clay, 3 tons; wet clay, 2 tons; loam, 1 ton.

## CHAPTER VIII.

### CHIMNEYS.

The form and size of the chimney is an important factor in the design of a boiler plant, and should receive careful consideration.

*Draft.*—The draft of a chimney is due to the difference in weight of the hot gases inside of the flue and of the cooler air surrounding it. The outside air being heavier tends to fall, and flowing into the base of the stack through the boiler furnace pushes the lighter air upward, thus producing a constant current as long as a fire is maintained to heat the air inside of the chimney. The draft of a chimney is usually expressed in inches of water. This means that if one end of a U tube be connected with the chimney flue while the other end is left open to the atmosphere, the difference in level of the water in the two legs of the tube will show the intensity of the draft.

A difference of ¼ inch indicates a moderate draft, ⅜ to ½ inch a fairly good draft, and ¾ to 1 inch a strong draft.

*Area and Height.*—The required area of cross section for a given chimney depends upon its height and the amount and kind of fuel to be burned. The conditions which affect chimney draft are so numerous and difficult to treat theoretically that it is generally considered best to use empirical formulas, derived from the study of existing plants. The formulas most commonly used are those of Kent, Christie, and Gale, of which the first two are the simplest to use. The constant used in Kent's formula is based upon the assumption that 15 pounds of coal will be burned upon each square foot of grate surface per hour under the draft produced by a chimney 80 feet high. In this formula the effective area of the chimney is computed from the actual area under the assumption that the gases for a depth of 2 inches next to the lining have no velocity, due to friction. That is, the actual diameter of a round chimney, or the side of a square chimney should be 4 inches greater than the effective area required to

carry off the gases. Kent's formula in its different forms is given below:—

$$E = \frac{0.3H}{\sqrt{h}} = A - 0.6\sqrt{A}$$

$$H = 3.33\,E\sqrt{h}$$

$$S = 12\sqrt{E} + 4$$

$$h = \left(\frac{0.3H}{E}\right)^2$$

in which

$E$ = effective area in square feet.
$A$ = actual area in square feet.
$H$ = horse power of boiler plant.
$S$ = side of square in inches.
$h$ = height of chimney in feet.

Table XXXII. has been computed by this method and will be found convenient for ready use. To find the pounds of coal that can be burned per hour with any chimney given in the

TABLE XXXII.*

SIZE OF CHIMNEYS WITH CORRESPONDING HORSE POWER OF BOILERS.

| Dia. in inches. | Height of chimney in feet. | | | | | | | | | | | Effective area in square feet = E | Actual area in square feet = A | Side of square in inches of approximate area. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 125 | 150 | 175 | 200 | | | |
| | Boiler horse power. | | | | | | | | | | | | | |
| 18 | 23 | 25 | 27 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | .97 | 1.77 | 16 |
| 21 | 35 | 38 | 41 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1.47 | 2.41 | 19 |
| 24 | 49 | 54 | 58 | 62 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 2.08 | 3.14 | 22 |
| 27 | 65 | 72 | 78 | 83 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 2.78 | 3.98 | 24 |
| 30 | 84 | 92 | 100 | 107 | 113 | ..... | ..... | ..... | ..... | ..... | ..... | 3.58 | 4.91 | 27 |
| 33 | ..... | 115 | 125 | 133 | 141 | ..... | ..... | ..... | ..... | ..... | ..... | 4.47 | 5.94 | 30 |
| 36 | ..... | 141 | 152 | 163 | 173 | 182 | ..... | ..... | ..... | ..... | ..... | 5.47 | 7.07 | 32 |
| 39 | ..... | ..... | 183 | 196 | 208 | 219 | ..... | ..... | ..... | ..... | ..... | 6.57 | 8.30 | 35 |
| 42 | ..... | ..... | 216 | 231 | 245 | 258 | 271 | ..... | ..... | ..... | ..... | 7.76 | 9.62 | 38 |
| 48 | ..... | ..... | ..... | 311 | 330 | 348 | 365 | 389 | ..... | ..... | ..... | 10.44 | 12.57 | 43 |
| 54 | ..... | ..... | ..... | 363 | 427 | 449 | 472 | 503 | 551 | ..... | ..... | 13.51 | 15.90 | 48 |
| 60 | ..... | ..... | ..... | 505 | 539 | 565 | 593 | 632 | 692 | 748 | ..... | 16.98 | 19.64 | 54 |
| 66 | ..... | ..... | ..... | ..... | 658 | 694 | 728 | 776 | 849 | 918 | 981 | 20.83 | 23.76 | 59 |
| 72 | ..... | ..... | ..... | ..... | 792 | 835 | 876 | 934 | 1023 | 1105 | 1181 | 25.08 | 28.27 | 64 |
| 78 | ..... | ..... | ..... | ..... | ..... | 995 | 1038 | 1107 | 1212 | 1310 | 1400 | 29.73 | 33.18 | 70 |
| 84 | ..... | ..... | ..... | ..... | ..... | 1163 | 1214 | 1294 | 1418 | 1531 | 1637 | 34.76 | 38.48 | 75 |
| 90 | ..... | ..... | ..... | ..... | ..... | 1344 | 1415 | 1496 | 1639 | 1770 | 1893 | 40.19 | 44.18 | 80 |
| 96 | ..... | ..... | ..... | ..... | ..... | 1537 | 1616 | 1720 | 1876 | 2027 | 2167 | 46.01 | 50.27 | 86 |

* From Kent's Mechanical Engineers' Pocketbook.

table, multiply the corresponding horse power by 5. Only that part of the table is filled in which corresponds to ordinary proportions between area and heights, and these general relations should be followed if calculations are made from the formula.

In looking over the chimney plans of a number of important power plants, the heights were found to vary from 20 to 30 times the diameter of the flue, and a chimney designed with proportions within these limits should under ordinary conditions give a good efficiency, and at the same time present a pleasing appearance. In Christie's formula $H = 3.24\ A\ \sqrt{h}$, it being assumed that 4 pounds of coal are burned per H. P. hour. The notation in the above is the same as in Kent's formula.

*Ratio of Grate to Chimney Area.*—Another method which is sometimes used is based upon the relation between the grate and chimney areas. Common practice has shown that good results may be obtained if the area of the chimney flue is made about 1/8 of the total area of all the grates connecting with it. The required height of chimney to produce different rates of combustion under various conditions may be obtained by the following formula:—

$$\sqrt{h} = \frac{F \times W \times 0.1}{A}$$

in which

$h$ = height of chimney in feet.
$F$ = area of boiler grate surface in square feet.
$W$ = pounds of coal burned per square foot of grate per hour.
$A$ = internal area of chimney flue in square feet.

The square root of $h$ for different heights is given in Table XXXIII.

TABLE XXXIII.

SQUARE ROOTS OF CHIMNEY HEIGHTS.

| h | √h | h | √h |
|---|---|---|---|
| 50 | 7.0 | 110 | 10.5 |
| 60 | 7.7 | 120 | 10.9 |
| 70 | 8.4 | 130 | 11.4 |
| 80 | 8.9 | 140 | 11.8 |
| 90 | 9.5 | 150 | 12.2 |
| 100 | 10.0 | 160 | 12.6 |

The formula will give approximately correct results for moderately free-burning bituminous, and medium to large anthracite coal; for free-burning bituminous coal deduct 10 per cent from height; for slow-burning bituminous add 10 per cent; for pea coal add 15 per cent, and for No. 3 buckwheat add 25 per cent.

The use of the above formula may best be illustrated by a practical example: What height of chimney will be necessary to burn 10 pounds of slow-burning bituminous coal per square foot of grate per hour under a battery of 6 boilers with a total grate area of 120 square feet? Area of chimney flue $= 120 \div 8 = 15$ sq. ft.

$$\sqrt{h} = \frac{120 \times 10 \times 0.1}{15}$$

$$\sqrt{h} = 8$$

Looking in Table XXXIII. we find that this corresponds to a height of chimney between 60 and 70 feet, which we will take as 65. Increasing this 10 per cent for the kind of coal used will give a required height of about 70 feet, or more accurately 72 feet.

*Height and Area for Different Coal.*—Some engineers determine the height of chimney by the grade of coal to be used and then compute the required flue area by one of the methods already given. The following heights have been found to give good results in plants of moderate size, and produce sufficient draft to force the boilers from 20 to 30 per cent above their rating; Free-burning bituminous coal, 75 feet; anthracite of medium and large sizes, 100 feet; slow-burning bituminous, 120 feet; anthracite pea coal, 130 feet; anthracite buckwheat coal, 150 feet.

For plants of 700 or 800 horse power and over, the chimney should not be less than 150 feet regardless of the kind of coal to be used. It will be seen that the above gives a somewhat higher chimney than the preceding formula, and for this reason is undoubtedly better adapted to power work when it is frequently desired to force the boilers or to change the grade of fuel. For heating purposes, or where the requirements are likely to remain more nearly constant, the formula may be used with suitable corrections for the grade of coal to be burned as stated.

*Form of Chimney.*—It will be found for a given area that a round chimney will have a greater capacity and also present less resistance to the wind, but in ordinary building construction the flue is usually of rectangular form, especially in the case of smaller plants; although iron or steel stacks of circular section are often used. In the construction of brick chimneys it is better to make the inside walls entirely separate from the outside, both in order to permit free expansion of the inner wall and also to secure the advantages of the non-conducting effect of an air space between the inside and outside walls. Such a construction is common for the chimneys of power plants, but is not ordinarily applied to those in buildings and used for heating purposes only.

The external diameter or breadth of a chimney at the base should be at least one tenth the height unless it is supported by some other structure. The taper should be from $\frac{1}{8}$ to $\frac{1}{4}$ inch per foot in height on each side.

*Foundation.*—The foundation of a large chimney is of great importance and should be laid out under the direction of an experienced engineer. The base of the foundation should be of such size that the pressure per square foot will not be over 1 ton for soft clay, nor over 2 tons for stiff clay, well-packed sand or loam. These loads are often exceeded in building foundations, but should not be in the case of chimneys.

When the soil is of low bearing power, pile foundations should be used, especially for large chimneys. The piles should be driven on 2 to $2\frac{1}{2}$ foot centers and the tops cut off below the level of the surface water. A layer of concrete 2 or 3 feet in thickness should be laid over the piles with their tops extending into it, and on top of this should be placed the regular foundation of brick or stone.

In computing the weight of a chimney the following figures may be taken: Granite masonry weighs from 150 to 170 pounds per cubic foot, and brickwork from 120 to 130 pounds.

*Thickness of Walls.*—In designing the outer shell of a chimney the following approximate method may be used for determining the thickness of walls: If the inside diameter at the top is less than 3 feet the walls may be 4 inches in thickness for the first

10 feet, then increasing 4 inches for each 25 feet downward. If the inside diameter is more than 3 feet and less than 5 feet, begin with a wall 8 inches in thickness, increasing 4 inches for each 25 feet downward. If the diameter is over 5 feet, begin with a 12-inch wall, increasing downward as before. The lining or core may be 4 inches in thickness for the first 20 feet from the top, 8 inches for the next 30 feet, 12 inches for the next 40 feet, 16 inches for the next 50 feet and 20 inches for the next 50 feet. Using this method for an outer wall 200 feet in height and assuming a cubic foot of brickwork to weigh 130 pounds, it gives a maximum pressure of 8.2 tons per square foot of section at the base, while a lining 190 feet high would have a maximum pressure of 8.6 tons per square foot. The safe load for brickwork may be taken from 8 to 10 tons per square foot, although the strength of best pressed brick will run much higher.

When the thickness of walls is determined as above it is well to take sections of the chimney at different elevations and compute the weight of brickwork above, and see what the pressure per square foot of section is at these points, as a check. The lining of a chimney carries its own weight only, while the outer shell must be made stable against wind pressure also.

*Wind Pressure.*—Power to withstand the overturning force of the wind requires a certain relation between the height, breadth, weight, and form of chimney. This is expressed in the formula

$$\frac{c\,d\,h^2}{b} = W$$

in which

$c = 56$ for square chimneys.
$= 35$ for octagon chimneys.
$= 28$ for round chimneys.
$b =$ breadth or diameter at base, in feet.
$d =$ average breadth or diameter, in feet.
$h =$ height, in feet.
$W =$ weight of chimney, in pounds.

In checking a chimney for stability by the above, if the actual weight is found to be equal to, or greater than $W$ given by the formula, then it will be stable against wind pressure.

*Chimney Cap.*—The external form of the top is a matter of appearance and may be designed to suit the taste. It should, however, be protected with a covering of tile or cast-iron plates to shed the rain and keep water from penetrating the brickwork. Iron ladders, either inside or outside the flue, and lightning rods are accessories which should be added to tall chimneys.

*Lightning Conductors.*—In the protection of a chimney against lightning it is essential that the points, if low, should be frequently spaced, and if a single point is used it should extend above the top of the chimney a distance equal to 1.2× the diameter of the flue. The points should be heavily gilded or coated with platinum, and should be cones having a height equal to the radius of their base. They should be supported on brackets built into the shaft of the chimney, so that no bends or at the best but slight ones will occur where the conductor clears the finial of the chimney.

Copper makes the best conductor, a tape or ribbon being used about ¾ inch wide by ⅛ to 3/16 inch thick. This should be carried down the chimney close to the ladder where it can be inspected from time to time. The ribbon should be secured to the shaft by copper clamps and no insulators should be used.

The ground plate should be of copper about 3 feet square and 3/16 inch thick and the ribbon should be brazed to the plate. This plate should be buried in crushed coke in a moist location. If desired a sufficient length of the copper tape to make the exposed area 18 square feet can be buried in coke or the ribbon may be connected with iron water pipes. In dry localities extra precautions should be used. It is a good plan to locate ground plates where the water from the roof leaders can reach them at times of storm.

*Lining.*—The inner core or lining is usually built of fire brick for a portion of its height. The core may be from two thirds to three fourths of the total height of the chimney, although some engineers prefer to carry it up the full height. In any case it should be entirely separate from the outer wall.

Openings should be left near the base for smoke pipe and cleanout. These may be either arched over the top or provided

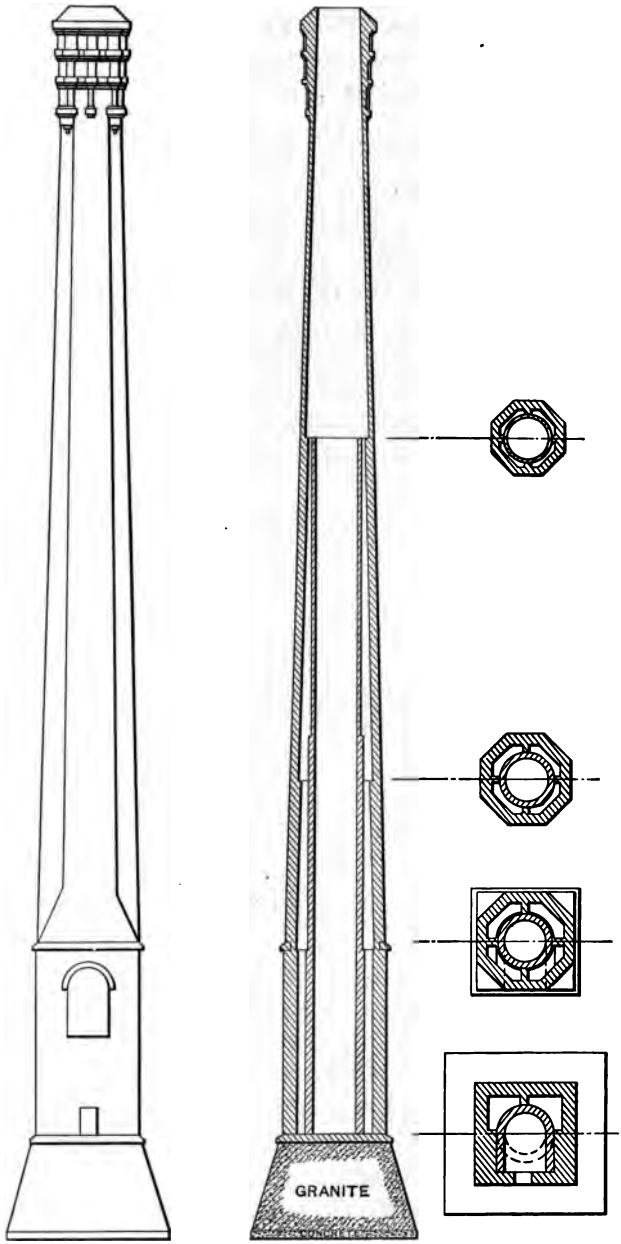



**Fig. 61. Chimney Details.**

with iron bearing bars. Fig. 61 will be found useful as a guide in the design of new chimneys.

*Steel Stacks.*—Stacks of boiler plate are quite commonly used at the present time. These are of two kinds; the first is designed to simply carry its own weight, and is supported against wind pressure by fastening to adjacent walls or by means of guy ropes. The second kind is made stable by heavy foundations and anchor bolts. Only the first will be taken up here. Steel stacks are made up in sections like the shell of a boiler, the end of one section being slipped into the next and the joint riveted.

Sometimes the sections are butted together and a covering ring placed over the joint and riveted to each piece. The stack usually rests upon a cast-iron ring or plate from 1 to 2 inches in thickness, which in turn is supported upon a foundation of stone or concrete.

TABLE XXXIV.

DIMENSIONS OF STEEL STACKS.

| Diameter of chimney in inches. | Height in feet. | Thickness of shell for first half of height in inches. | Thickness of shell for second half of height in inches. | Diameter of rivets in inches. | Pitch of rivets in inches. | Total weight of stack in pounds. |
|---|---|---|---|---|---|---|
| 15 | 40 | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{3}{4}$ | 3 | 1400 |
| 18 | 45 | $\frac{5}{16}$ | $\frac{1}{4}$ | $\frac{3}{4}$ | 3 | 2500 |
| 20 | 50 | $\frac{5}{16}$ | $\frac{1}{4}$ | $\frac{3}{4}$ | 3 | 3000 |
| 24 | 60 | $\frac{5}{16}$ | $\frac{1}{4}$ | $\frac{3}{4}$ | 3 | 4900 |
| 30 | 75 | $\frac{3}{8}$ | $\frac{5}{16}$ | $\frac{3}{4}$ | 3 | 8300 |
| 36 | 90 | $\frac{3}{8}$ | $\frac{5}{16}$ | $\frac{3}{4}$ | 3 | 11750 |
| 42 | 105 | $\frac{3}{8}$ | $\frac{5}{16}$ | $\frac{3}{4}$ | 3 | 15700 |
| 48 | 120 | $\frac{3}{8}$ | $\frac{5}{16}$ | $\frac{3}{4}$ | 3 | 21450 |

When the side of the stack is cut away for connecting the smoke pipe, suitable means should be taken to strengthen the shell at this point. This may be done by riveting angle or tee bars to the plates at the sides of the opening, extending them for some distance above and below it.

Stiffening pieces are sometimes carried across the top and bottom of the opening, with a supporting piece placed vertically across its center. Table XXXIV. gives usual and safe dimensions for supported stacks.

## CHAPTER IX.

### MECHANICAL DRAFT.

Mechanical draft is often used in large boiler plants, either as a substitute for a tall chimney or for increasing the power of a chimney already in use, and is also necessary with certain types of mechanical stokers.

*Advantages.*—With mechanical draft the boilers may be run at their maximum capacity without regard to outside weather conditions, and as the draft is independent of the temperature of the chimney gases it allows of their being cooled to a comparatively low degree, thus making available a certain quantity of heat which may be utilized in economizers for heating the feed water. A saving of 10 to 20 per cent in fuel is often made in this way.

Poorer grades of fuel may be used than is possible with a natural draft, and the capacity of a boiler may be increased from 30 to 40 per cent for continuous working, and much more for short runs. This is especially useful in the case of electric lighting and power stations, where the maximum quantity of steam is required for only a few hours per day. Forcing a boiler beyond a certain limit lowers its efficiency, but for short periods this is often more than offset by the reduced first cost of the plant and the smaller operating expenses.

Ease of regulation is another advantage of mechanical draft of considerable importance.

*Rate of Combustion.*—The rate of combustion with mechanical draft varies with the intensity of the draft, and in ordinary heating and power work usually ranges from about 15 to 30 pounds of coal per square foot of grate per hour. In marine and locomotive boilers it is much higher, varying from 30 to 50 pounds in the former, and from 60 to 125 in the latter.

*Efficiency.*—If the rate of combustion be increased in the case of a boiler running at maximum efficiency, while the grate area remains the same, the rate of evaporation per pound of coal will

be reduced; but if the grate be made of such size that the *total* quantity of fuel burned per hour remains constant, a certain increase in efficiency will be observed.

This is due principally to the deeper fires which may be carried with a forced draft, and to the more intimate contact of the air with the coal. The increased pressure forces the air into spaces between the fuel which could not be reached under a lesser draft, and, as a greater proportion of the air is therefore consumed in combustion, the total quantity is reduced, resulting in a hotter fire and a greater radiation of heat to the boiler surfaces.

*Grate Surface.*—It has been stated in a previous chapter that under ordinary conditions a combustion of about 0.3 pound of coal per square foot of heating surface per hour has been found to give the most satisfactory results. This should still be kept in mind when applying mechanical draft to a boiler.

As the rate of combustion is increased the total amount of coal consumed should be kept approximately the same by reducing the size of grate. Assuming 15 square feet of heating surface per horse power for fire-tube boilers, and 10 for water-tube, we have the following grate areas per horse power for higher rates of combustion as given in Table XXXV.

TABLE XXXV.

GRATE AREAS PER HORSE POWER FOR MECHANICAL DRAFT.

| Pounds of coal burned per sq. ft. of grate per hour. | Square feet of grate per horse power. | |
|---|---|---|
| | Fire tube boilers. | Water tube boilers. |
| 15 | 0.30 | 0.22 |
| 18 | 0.25 | 0.19 |
| 21 | 0.22 | 0.16 |
| 24 | 0.20 | 0.14 |
| 27 | 0.17 | 0.12 |
| 30 | 0.15 | 0.11 |

*Air Required for Combustion.*—Theoretically, about 12 pounds of air are required to burn 1 pound of average coal or coke. In practice, however, with natural draft, it is necessary to supply about twice this amount to secure complete combustion, owing to the difficulty of bringing the air into contact with the entire body of coal. With mechanical draft and deeper fires, this quantity may usually be reduced to about 18 pounds per pound of

coal, which is equivalent in round numbers to about 230 cubic feet, at a temperature of 60° F. As all of the air supplied has to be raised to the temperature of the furnace gases, this reduction should, theoretically, increase the efficiency of the boiler about. 4 per cent under usual conditions. This is upon the assumption that the gases pass to the chimney at a temperature of 500° F. in each case. If an economizer is used, the gases may be cooled to a considerably lower temperature by the use of mechanical draft than is possible with a chimney, unless it be of excessive height, thus increasing the efficiency of the plant still more.

*Intensity of Draft.*—The draft, or pressure, required will vary in different cases, depending upon the quality and fineness of the fuel, the length and size of the smoke passages and the number of bends in the pipe. In ordinary practice with stationary boilers it usually runs from 1 to 2 inches of water column.

TABLE XXXVI.

AIR PRESSURE REQUIRED FOR DIFFERENT FUELS.

| Kind of fuel | Pressure required in inches of water |
|---|---|
| Good steam coal, | 0.4 to 0.7 |
| Ordinary slack, | 0.6 to 0.9 |
| Very fine slack, | 0.7 to 1.1 |
| Semi-anthracite, | 0.9 to 1.2 |
| Anthracite slack, | 1.3 to 1.8 |

Table XXXVI., tabulated by Dr. R. H. Thurston, gives the pressure required to properly burn different grades of fuel. If the smoke passages are long, or the flow of gases through them is restricted in any way, the pressures given in this table should be correspondingly increased.

### Systems of Mechanical Draft.

There are three systems of mechanical draft commonly applied to stationary boilers, as follows:—

1. The steam jet, by means of which steam and air are blown into the ash pit.

2. Forced draft or the closed ash pit system, in which a fan is employed to discharge air under pressure into the ash pit.

3. Induced draft, where an exhaust fan is placed in the smoke flue to produce a suction. In the latter arrangement the gases pass through the fan and are discharged into the chimney or uptake.

*Steam Jet System.*—This is usually the most wasteful method of producing a draft, but has certain advantages in the burning of cheap coals high in ash, as the decomposition of the steam into

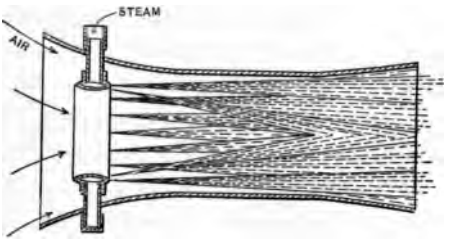



**Fig. 62. Argand Blower.**

hydrogen and oxygen in the bed of hot coal tends to prevent the formation of clinker. The expense of running a steam jet is that of the steam used and the heat required to superheat it to the

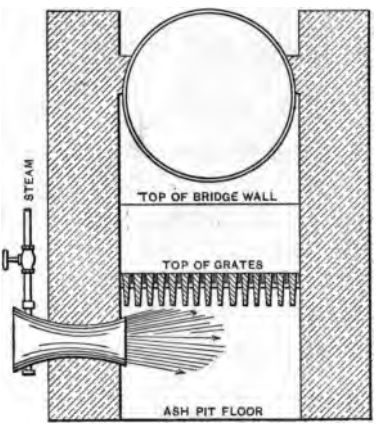



**Fig. 63. Location of Argand Blower.**

temperature of the chimney gases. A series of tests made at the New York navy yard some years ago showed the amount of

steam required to vary from 8 to 20 per cent of the total generated by the boiler. The percentage required is found to be larger as the size of the plant diminishes. The simplicity and low cost of the steam jet are among its advantages.

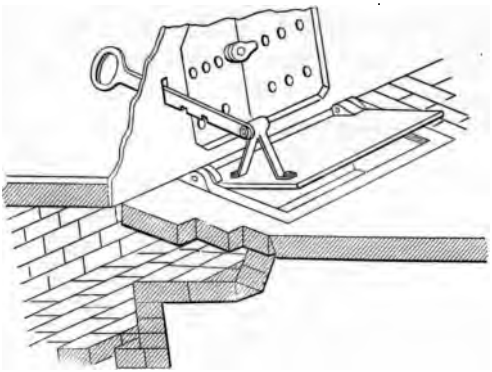


**Fig. 64. Admission of Air for Forced Draft.**

Fig. 62 shows the Argand blower, a form of steam jet commonly used with the McClave grate. It is connected with the ash

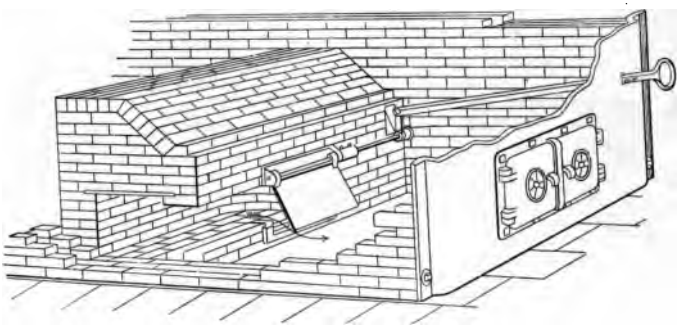


**Fig. 65. Forced Draft—Damper in Bridge Wall.**

pit as shown in Fig. 63, and delivers a large volume of air mixed with steam beneath the grates. The steam is discharged through a large number of small openings in a metal ring and the air is drawn into the surrounding nozzle by the strong suction produced. (See Fig. 62.)

*Closed Ash Pit System.*—This system is the most easily applied to existing plants where it is desired to increase the draft for burning cheaper grades of fuel, and is also necessary in case under-fed stokers of the retort type are used. The air is usually introduced through openings in the bridge wall or in the bottom of the ash pit. Care should be taken to distribute the air as evenly as possible in order to prevent holes being blown through the fire. This may be accomplished by the use of deflecting dampers which throw the air downward as it enters the ash pit.

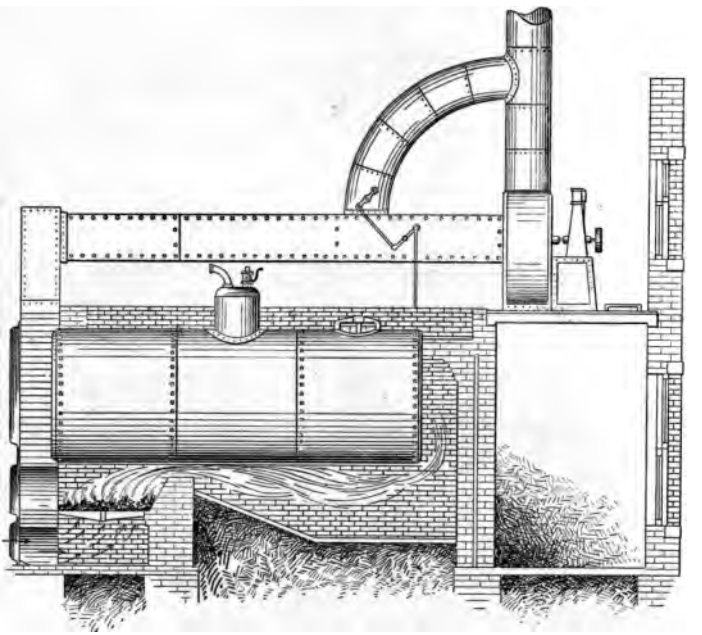


**Fig. 66. Induced Draft System.**

The dampers used for this purpose by the B. F. Sturtevant Company are shown in Figs. 64 and 65. The pressure within the ash pit and furnace tends to blow ashes and flame into the fire room if forced too hard, but under a moderate draft but little trouble will be experienced from this cause. Care should always be taken to close the damper in the blast pipe before opening the furnace or ash pit doors.

*Induced Draft System.*—With this system a partial vacuum is produced within the furnace, and its action is therefore practically the same as the natural draft of a chimney. It is more easily controlled than the other systems, and as the leakage is inward, all inconvenience from flame and dust at the fire and ash doors is avoided, and the fires may be made to burn more evenly over the entire surface than when forced draft is used.

## TABLE XXXVII.

FAN DIMENSIONS, QUANTITY OF AIR AND HORSE POWER FOR MAINTAINING PRESSURE IN ASH PIT.

For forced draft, temperature of air 60 degrees F.

| Diameter of fan | Cubic feet of air delivered to furnace per minute | Pressure in inches of water. | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | .5 | | .75 | | 1.00 | | 1.25 | | 1.50 | | 2.00 | | 2.50 | |
| | | Revolutions per minute | Horse power | Revolutions per minute | Horse power | Revolutions per minute | Horse power | Revolutions per minute | Horse power | Revolutions per minute | Horse power | Revolutions per minute | Horse power | Revolutions per minute | Horse power |
| Ft. In. | | | | | | | | | | | | | | | |
| 2 6 | 4200 | 510 | 1.6 | 560 | 1.8 | 600 | 1.9 | 640 | 2.1 | 710 | 2.3 | 780 | 2.5 | 850 | 2.7 |
| 3 | 5800 | 430 | 2.2 | 460 | 2.4 | 490 | 2.6 | 530 | 2.8 | 590 | 3.1 | 640 | 3.4 | 710 | 3.8 |
| 3 6 | 7800 | 360 | 3.0 | 400 | 3.3 | 420 | 3.5 | 450 | 3.8 | 500 | 4.2 | 550 | 4.6 | 610 | 5.1 |
| 4 | 10000 | 320 | 3.9 | 350 | 4.2 | 370 | 4.4 | 400 | 4.9 | 440 | 5.4 | 480 | 5.9 | 530 | 6.5 |
| 4 6 | 12400 | 290 | 4.8 | 310 | 5.2 | 330 | 5.6 | 360 | 6.0 | 400 | 6.7 | 430 | 7.3 | 470 | 8.0 |
| 5 | 15200 | 250 | 5.9 | 270 | 6.4 | 290 | 6.8 | 310 | 7.4 | 350 | 8.2 | 380 | 8.9 | 420 | 9.8 |
| 5 6 | 18200 | 230 | 7.0 | 250 | 7.7 | 270 | 8.2 | 300 | 8.8 | 330 | 9.8 | 360 | 10.6 | 390 | 11.8 |
| 6 | 21400 | 210 | 8.3 | 230 | 9.1 | 250 | 9.6 | 280 | 10.4 | 310 | 11.5 | 320 | 12.5 | 350 | 13.9 |
| 7 | 28800 | 180 | 11.2 | 200 | 12.2 | 210 | 13.0 | 230 | 14.0 | 250 | 15.5 | 280 | 16.8 | 300 | 18.7 |
| 8 | 37200 | 160 | 14.4 | 170 | 15.7 | 190 | 16.7 | 200 | 18.1 | 220 | 20.1 | 240 | 21.8 | 270 | 22.5 |
| 9 | 46800 | 140 | 18.1 | 160 | 19.8 | 170 | 21.1 | 180 | 22.7 | 200 | 25.3 | 220 | 27.4 | 240 | 30.3 |
| 10 | 57400 | 130 | 22.2 | 140 | 24.3 | 150 | 25.8 | 160 | 27.9 | 180 | 3.1 | 200 | 33.6 | 210 | 37.2 |

A specially constructed fan with self-cooling bearings is required for this system, as the gases passing through it are at a high temperature.

Fig. 66 shows in a general way the method of connecting the fan with the smoke pipe and chimney. This arrangement, however, can be varied to suit different conditions.

### Fans for Forced Draft.

The common form of steel plate encased fan is used for mechanical draft. This is usually driven by a direct-connected steam engine, although the belted type may be used if preferred. Regu-

lation is generally obtained by means of a throttle valve in the steam pipe, which is operated automatically by the pressure in the boiler, thus changing the speed of the fan as may be required to give the proper draft to maintain a constant boiler pressure.

Table XXXVII. gives size and speed of fan, quantity of air delivered, and horse power required for maintaining different pressures in the ash pit when the fan is located reasonably near the boiler. The air quantities are based on a velocity of 2,000 feet per minute through the fan outlet. The method of computing the quantities given in the table is described in detail in chapter X., Part III.

When the required volume of air comes between those given in Table XXXVII. the speed may be increased or diminished to make up for small differences, but for any considerable variation the width of the fan should be changed, keeping the diameter and speed the same in order to maintain the pressure, which depends directly upon the peripheral velocity.

TABLE XXXVIII.

FAN WIDTHS.

| Diameter of wheel | | Width of wheel |
|---|---|---|
| Ft. | In. | In. |
| 2 | 6 | 16 |
| 3 | | 19 |
| 3 | 6 | 22 |
| 4 | | 25 |
| 4 | 6 | 28 |
| 5 | | 31 |
| 5 | 6 | 34 |
| 6 | | 37 |
| 7 | | 43 |
| 8 | | 50 |
| 9 | | 56 |
| 10 | | 62 |

*Fan Calculations.*—The air volumes in the tables are computed on the basis that the width of fan wheel at the inlet is 0.52 of the diameter. This gives the widths tabulated in Table XXXVIII., from which the volume per inch in width can be computed for any given diameter of wheel.

*Example.*—It is desired to burn 1,800 pounds of coal per hour under a battery of boilers using a forced draft of 1.25 inches of water column. What size and speed of fan will be required, and what horse power of engine?

Pounds of coal per minute = 1,800 ÷ 60 = 30, requiring 30 × 230 = 6,900 cubic feet of air.

From Table XXXVII. we find that a 3½-foot fan running at 450 revolutions per minute will deliver 7,800 cubic feet of air per minute under a pressure of 1.25 inches of water, and requires 3.8 H. P. The air volume required is 6,900 cubic feet, or 6,900 ÷ 7,800 = 0.88 of that delivered by a standard wheel 22 inches in width, so that under the above conditions the required width of wheel would be 22 × 0.88 = 20 inches.

Theoretically, the horse power varies as the volume of air moved, but actually the friction of the fan forms a considerable part of the load, and this would be affected but little by any slight change in the width, so in practice it is best to take the horse power directly from the table without change.

In the above example a standard 3½-foot fan would probably be used without any reduction in width, and any excess of air would be cared for by automatic regulation of speed. In the case of large fans this is of more importance and must be dealt with accordingly.

### Fans for Induced Draft.

When induced draft is used, a much larger volume of air must be handled by the fan, due to the higher temperature and resulting expansion. The weight, and consequently the volume of air at 60° which is necessary for the combustion of a given weight of fuel, is of course the same whether forced into the ash pit or drawn in by suction, but in the latter case, when the heated gases reach the fan the volume is much increased, and the density correspondingly decreased.

If a fan supplying forced draft should be used to produce an induced draft of the same intensity the following changes would take place, their magnitude depending upon the temperature of the gases: First, the speed would have to be increased in order to maintain the same pressure; second, the power necessary to drive the fan at the higher speed would be greater than before; and third, the volume of air supplied to the furnace would be reduced.

## CHAPTER X.

### LIQUID FUEL.

The use of oil as a fuel is becoming a matter of considerable importance in certain sections of the country, both for stationary boilers and locomotives. Various steamship lines have also equipped some of their boats for burning oil with very satisfactory results. The use of oil for this purpose has thus far been confined principally to the oil producing regions, but numerous plants in other sections have been operated successfully in competition with coal.

*Advantages.*—The principal advantages claimed for oil as a fuel as compared with coal are: The absence of soot and ashes, resulting in clean heating surfaces and increased steaming capacity of the boilers; a more even distribution of heat in the combustion chamber, as it is not necessary to open the feed doors to supply fresh fuel; a reduction in the cost of handling, as this is done mechanically or by gravity; absence of dust, ashes and clinkers and ease of regulating the fires.

*Disadvantages.*—Opposed to these advantages are: danger of explosion under certain conditions, if stored in too warm a place; higher cost in many localities; and excessive noise from the burners if not properly constructed and adjusted.

*Kinds of Oil Used.*—There are two kinds of oil in general use for this purpose. One is the crude petroleum as it comes from the wells, and the other is the residuum which is left after the lighter oils have been distilled.

*Oil Compared with Coal.*—The heat produced by the combustion of 1 pound of petroleum will vary from about 17,000 to 20,000 heat units as against 12,000 to 14,000 for an equal weight of coal, making, on an average, the heating value of 1 pound of petroleum equivalent to approximately 1½ pounds of coal. In actual practice the ratio is found to be somewhat greater, and under ordinary conditions from 3½ to 4½ barrels (42 gallons

per barrel) of oil are considered equivalent to 1 ton of coal (2,000 pounds).

Taking this as a basis the relative costs of the two fuels for any given locality can be approximately computed, due allowance being made for the reduction of labor in the case of oil. For a more accurate comparison a careful analysis of both the coal and oil should be made to determine their heating values.

*Method of Burning.*—Oil fuel does not burn as a liquid, but must first be reduced to a vapor. After this change has taken place it is mixed with the right proportion of air and burned in a chamber kept at a proper temperature.

Means for vaporizing the oil, for insuring an adequate supply of air, and for producing an intimate mixture within a chamber kept at a suitable temperature, must therefore form the foundation of all methods of oil burning.

*Oil Burners.*—There are many different forms of burners on the market, but they may be divided into three general classes, as follows:—

Mechanical spray burners, in which the oil is forced under high pressure through a nozzle made of such form as to break it up into a fine spray and thus render it inflammable.

Air burners, where the liquid is held in suspension and driven into the furnace by means of a jet of compressed air.

Steam jet burners, in which the oil is injected in the form of a spray by means of a jet of steam, and the right amount of air allowed to mix with it, partly by suction through an opening in the burner and partly by way of an opening from the ash pit into the furnace.

Vapor burners are also used where the oil is first volatilized in a separate chamber and then burned in the furnace in the form of gas.

*Description of Burners.*—The Korting mechanical spray burner is shown in Fig. 67. The oil is first heated to a temperature of about 270° and then forced under a pressure of about 50 pounds per square inch through a nozzle having a small orifice in which is an adjustable spindle with spiral grooves. The rotary motion thus given to the oil causes it to break into a spray from the effect of centrifugal force as soon as it leaves the nozzle.

In another form the fuel passes through a minute orifice and is divided into a fine spray by striking against a cutter placed a short distance in front of the orifice.

The use of compressed air and steam in a burner is very much the same. In case air is used, it should first be heated to a high temperature by passing through a fire brick duct built into the furnace or combustion chamber, or by special means adapted to the particular type of burner in use.

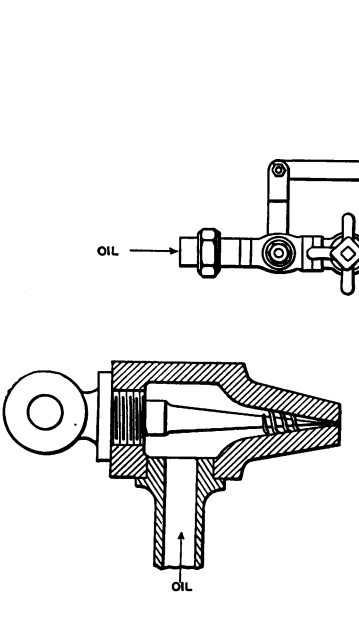



Fig. 67. Korting Mechanical Spray Burner.

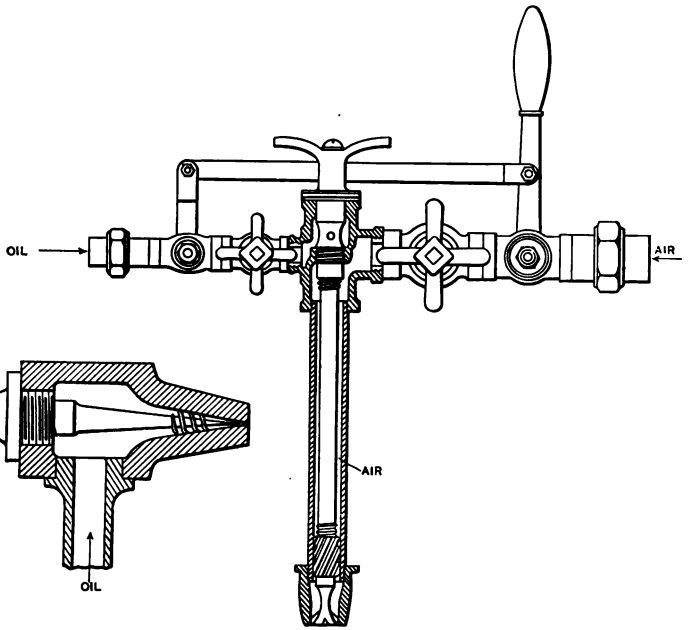



Fig. 68. Grundell-Tucker Air Burner.

The Grundell-Tucker air burner is shown in Fig. 68. Both the air and oil are supplied to the burner under a pressure of about 30 pounds. The oil is ordinarily heated by a steam coil to a temperature of 120 to 130 degrees, and the air to about 350 degrees. The high temperature of the latter is due in part to mechanical compression and partly to the absorption of heat while passing through an air chamber surrounding the burner.

Fig. 69 shows a section through the Hayes burner, which uses steam instead of compressed air. For securing the best results with burners of this type steam at a high pressure is desirable.

The Reed burner, shown in Fig. 70, is a combination steam and air burner. The air supply for burners of this design is usually heated by passing through flues built in the brickwork of the setting as already described.

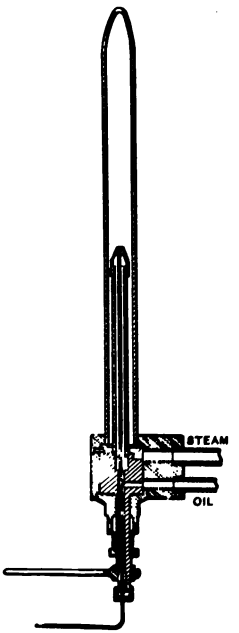



**Fig. 69. Hayes Burner, which Uses Steam.**

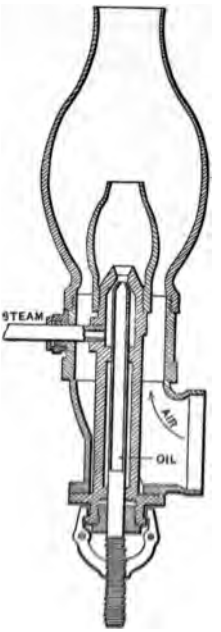



**Fig. 70. Reed Combined Air and Steam Burner.**

In some other forms the oil is heated in the burner itself by forcing it through passages surrounded by steam.

*Advantages of Different Types of Burners.*—Tests made some time ago by the U. S. Government of different types of burners seemed to indicate that the best results were obtained by the use of either steam or air alone, rather than by a combination of the

two within the burner. Burners using steam are considered preferable for large furnaces with much brickwork, as they spread the flame more and thus fill the entire furnace.

Air burners concentrate the flame at the point of contact, and are very destructive to plates and brickwork.

Burners are made in all sizes up to 300 H. P. or more, but a number of smaller burners are found to use less fuel per horse power than a single large one. One burner for each 50 or 75 H. P. has been found to give the most satisfactory results under ordinary conditions. A burner placed in the center of each fire door is the arrangement usually employed.

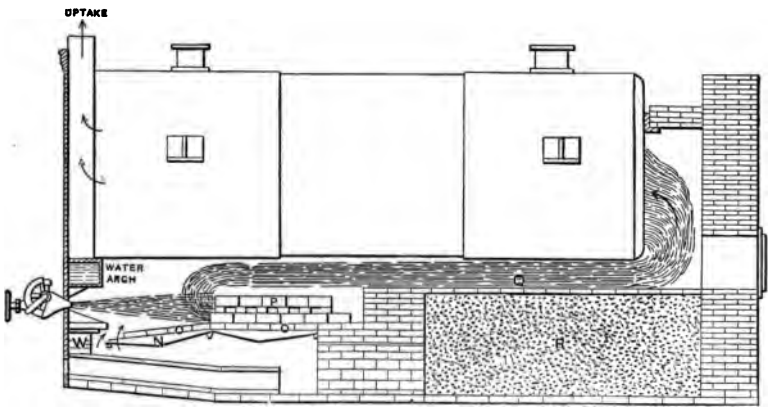



Fig. 71. Section of Furnace for Oil Burning.

*Furnace Construction for Oil Fuel.*—The construction of the furnace varies with the kind of boiler and type of burner used. The common method is to spray the oil against brickwork and along the grates, which should be covered with fire brick. This keeps the brickwork in an incandescent state and assists in the combustion. The covering for the grate may consist of broken fire brick laid in a loose bed so as to admit plenty of air. The grates should be of good length, with a bridge wall placed at the rear for the flames to strike against. Air may be admitted through the ash pit doors in the usual way. A form of furnace

used with the Williams burner and others of the combined steam and air type is shown in Fig. 71. Another method is to cover the grates with asbestos board, on top of which is loosely placed a layer of fire brick on the flat and the whole plastered over with fire clay. Uncovered spaces of about 70 square inches should be left under each 50 H. P. burner for admitting air from the ash pit. A "cascade" or "spatter wall" of fire brick on edge with narrow spaces between them is placed in front of the bridge wall, and the burners are so directed that the flame will strike the cascade wall about one third the way up from the bottom.

Some types of burners can be bolted directly to the grate bars without change in the furnace construction.

Whatever kind of burner is used it should be so arranged that the flame will not be thrown directly against the boiler plates, for if this is done they will soon become overheated and badly injured. Manufacturers of burners will furnish detailed descriptions of the best form of furnace to be used in connection with their particular type of burner.

*Storage of Oil.*—The best way of storing oil for fuel is in an underground tank made of boiler iron and placed outside of the boiler room. The oil is either pumped to the burners or forced by means of steam or air pressure, admitted to the upper part of the storage tank. When steam is used for this purpose it also serves to warm the oil so it will flow more freely through the piping to the burners. If a pump is employed a steam coil is usually placed in the tank and supplied either with live steam or exhaust from the pump. In some systems the oil is warmed and purified by admitting hot water from the boilers into the lower part of the storage tank.

In order to get the best results, the oil should be supplied to the burner at a constant pressure. This is commonly done in one of two ways; a relief valve may be placed in the delivery pipe from the pump which will discharge back into the tank when the pressure reaches a given point, or the oil may be pumped to a standpipe, from which it flows under a constant head to the burners. When a standpipe is used the insurance companies require the use of an automatic valve which will drain the oil from

the standpipe when the steam pressure drops below a given point. This is to prevent flooding the furnace with oil when there is not sufficient pressure to atomize it. Fig. 72 shows the arrangement of pipe connections for using a pump and standpipe.

*Danger from Liquid Fuel.*—If the oil commonly used for fuel is heated much above 140° gases will be formed. These gases, while not explosive by themselves, will ignite when in contact with air and cause violent explosions.

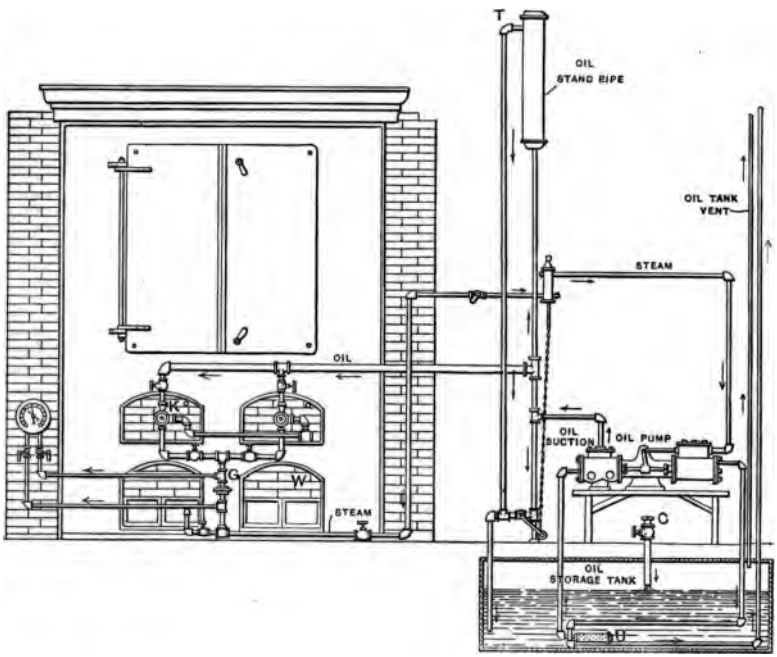



**Fig. 72. Arrangement When Pump and Standpipe are Used.**

Gases may be formed in three ways: First, by overheating, either from the sun or by nearness to the furnace; second, if air is forced through the oil it will become saturated with inflammable products; and third, gases will be formed if the oil is violently churned or agitated, as by passing it continuously through a pump by connecting the discharge from a relief valve

directly with the pump suction. The oil itself is not easily inflammable, and a lighted match or red hot coal may be dropped into it without igniting it. With ordinary precautions the danger is very slight, and when used in connection with stationary boilers need not be seriously considered.

Some engineers recommend the use of a residuum from which the lighter products have been distilled to such a degree that the flash point is raised to a comparatively high temperature, thus practically eliminating the factor of danger under any conditions where the fuel is likely to be used.

## CHAPTER XI.

### BOILER ACCESSORIES.

*Water Glass and Gauge Cocks.*—It is of much importance that the water level in a boiler be easily ascertained at any time. If it becomes too low there is danger of overheating the plates; and if too high, priming is likely to occur. The water level is indicated by the water glass and gauge cocks. The former consists of a strong glass tube about a foot in length, having the ends connected to the boiler by means of suitable fittings, so that the water level within it will be the same as that in the boiler, and always in sight. As the glass needs frequent cleaning or renewing, it is provided with cocks for shutting it off from the boiler; and as it is liable to break occasionally from various causes, the cocks are sometimes provided with small checks which close upon any sudden rush of steam or water through them. If dirty

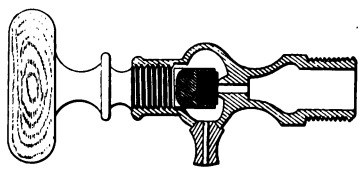


Fig. 73. Gauge Cock.

water is used or if foaming occurs, the level indicated by the glass is unreliable. If the steam and water connections are long, they should be of extra large size.

There are many forms of gauge cocks in use, varying with different makers. The pattern shown in Fig. 73 is commonly used on boilers where they may be easily reached by the attendant. Others are especially adapted for use on water-tube or vertical boilers, where they are necessarily placed at some distance from the boiler room floor. These are usually opened by raising a weight or drawing out a valve stem, and may be operated by a chain or lever brought down to a point near the floor. There

are usually three cocks, one placed at the highest point that it is desired to have the water rise, one at the lowest level, and one half way between. Instead of connecting the water glass and gauge cocks directly with the boiler head, it is more common to connect them with a cast iron chamber called a "combination box" or "water column," which in turn is connected at top and

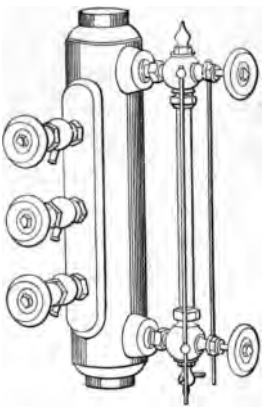


**Fig. 74. Water Column.**

**Fig. 75. Mechanism of Pressure Gauge.**

bottom with the boiler by 1¼-inch pipes. Fig. 74 shows a common arrangement. The bottom of the glass is sometimes placed on a level with the top of the upper row of tubes, but it is con-

TABLE XL.

SIZE OF FEED PIPE.

| Diameter of boiler, inches | Size of feed, inches |
|---|---|
| 36 | 1 |
| 42 | 1 |
| 48 | 1 |
| 54 | 1½ |
| 60 | 1½ |
| 66 | 1¾ |
| 72 | 1¾ |

sidered better practice to place it about 2 inches above the tubes, so that they will still be covered when the water disappears from the glass.

*Feed Pipe.*—The feed connections to a boiler, with the exception of that part exposed in the smoke bonnet, are always made of brass in the best class of work. The small section referred to should be of extra heavy wrought iron. The branch to each boiler should be provided with a gate or globe valve and a check valve; the former being placed next to the boiler.

Table XL. gives suitable sizes of feed pipes for boilers of different diameters.

*High and Low Water Alarms.*—There are numerous devices for indicating the water level by means of floats so arranged that when the water becomes too high or dangerously low a whistle gives warning. Other forms are arranged to act both as a low water alarm and automatic boiler feed. When the water level drops to a given point, the action of the float opens the feed valve and admits more water to the boiler. If for any reason the feed apparatus fails to work and the water level drops still lower, the whistle valve is opened and the alarm given.

*Pressure Gauges.*—The dial gauge is almost universally used. It is designed on the principle that a flattened tube, bent to a curve and closed at one end, tends to become straight when subjected to an internal pressure. The tube, which is usually oval in section, is bent into the arc of a circle as shown in Fig. 75. One end is fixed and connected with the boiler pressure. The other end is closed and free to move. By means of levers and a curved rack and pinion, the motion of the free end is multiplied and the internal pressure is indicated by a pointer upon a dial.

The pipe connecting the gauge with the boiler should contain a bend or coil called a siphon, which will remain filled with water, thus preventing the steam itself from entering the tube. Whenever a siphon is selected care should be taken that it has a capacity for water sufficient to fill the tube of the gauge. If the connections are such that the pipe leading from the boiler extends downward to the gauge, thus forming a pocket to become filled with water, a correction should be made by moving the pointer on its pinion to offset the weight of the water column which acts upon the gauge, in addition to the steam pressure. If a gauge is to be connected up in this way, the height of the water column

should first be determined, and the necessary changes made before the gauge leaves the works. In case several boilers are set in battery, each should have its own pressure gauge, which should be connected directly to the boiler and not to the steam pipe.

*Recording Gauges* are often used in large plants for keeping a continuous record of the boiler pressure during the entire day. These are similar in construction to an ordinary pressure gauge, with the addition of a revolving paper dial run by clockwork. The pointer extends over the dial from one side, and the end is provided with a pen, which traces a line on the dial at a distance from the center proportional to the steam pressure. A glance at the record thus made will show the steam pressure at any time during the day or night.

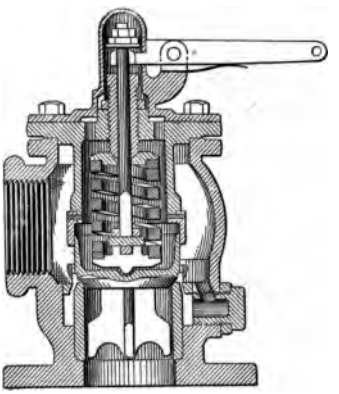


**Fig. 76. Pop Safety Valve.**

*Safety Valves.*—These are constructed in several forms, but in every case they consist of a valve opening outward and held in place by a weight or spring. The lever safety-valve is the older form, and is used to a considerable extent at the present time, especially on low pressure heating boilers. The valve in this case is held in place by a weight suspended on a lever. The force required to lift the valve is regulated by shifting the position of the weight upon the arm. When the valve becomes leaky it should be made tight by regrinding; additional weights should never be added for this purpose. This type of valve has several defects,

among which are the following: It does not close promptly when the pressure is reduced, it is likely to leak after it is closed, and it can be easily overloaded or wedged in place. The spring or pop safety valve overcomes these defects in a large degree. A valve of this form is shown in Fig. 76. These valves open when the steam pressure is sufficient to overcome the tension of the spring, and can be adjusted for different pressures by means of a nut and screw at the top, which increases or diminishes the tension on the spring. They are often provided with a "lock-up" attachment so that the regulating parts cannot be tampered with either by accident or design. The safety valve should be connected by a separate nozzle directly to the boiler without pipe or elbow, and should be opened every day by means of a lever and chain to see that it is in working order.

TABLE XLI.*

DIAMETERS OF LEVER SAFETY VALVES.

| Lever Safety Valves. | | | | | | | |
|---|---|---|---|---|---|---|---|
| Diameter of valve, inches, | 1 | 1¼ | 2 | 2½ | 3 | 3½ | 4 |
| Horse power of boiler, | 20 | 30 | 40 | 50 | 60 | 70 | 80 |

* From Kent's Mechanical Engineer's Pocketbook.

TABLE XLII.*

DIAMETERS OF POP SAFETY VALVES.

| Diameter of valve, inches | Horse power of boiler | Diameter of valve, inches | Horse power of boiler |
|---|---|---|---|
| 1 | 5 to 10 | 3 | 75 to 100 |
| 1¼ | 10 to 20 | 3½ | 100 to 125 |
| 1½ | 20 to 30 | 4 | 125 to 150 |
| 2 | 30 to 40 | 5 | 150 to 200 |
| 2½ | 40 to 75 | | |

* From Kent's Mechanical Engineer's Pocketbook.

There are many rules for determining the size of a safety valve, each giving a different result. For lever valves the sizes given in Table XLI. may be used with satisfactory results. Where a diameter of over 4 inches is called for it is customary to use two smaller valves having an equivalent capacity.

For pop valves the sizes given in Table XLII. may be used. These correspond well with the average capacities given by dif-

ferent makers and with results obtained from the most approved methods of calculation.

*Fusible Plugs.*—Danger from overheating the plates of a boiler is guarded against by means of a fusible or safety plug, which consists of a brass bushing with a core of some fusible metal which melts before an excessive temperature is reached. The government requires that pure Banca tin be used for this purpose on the boilers of steam vessels. In case of low water the plug melts and the steam and water blowing into the furnace will check the fire to some extent, and also give warning to those in charge. In a horizontal tubular boiler the fusible plug is screwed into the rear head at a point about 2 inches above the upper row of tubes; in a vertical boiler it is placed in the lower tube sheet or a little above the crown sheet in one of the tubes; and in the case of a water-tube boiler it is placed in the lower portion of the upper drum. To be efficient the plug should be of good length and the core made tapering in form, with its larger end toward the steam pressure to prevent its blowing out. Fig. 77 shows a common form to be screwed into the plate from the outside.

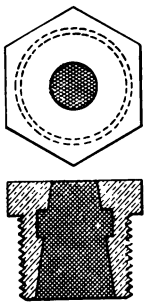


Fig. 77.
Fusible Plug.

### Injectors.

*Injectors.*—The injector is used extensively in both stationary and marine practice and exclusively upon locomotives. Its advantages are its compactness and simplicity, having no moving parts when in operation except a light check in certain forms. In stationary work the injector is often used in connection with a pump as a safeguard in case of a breakdown. The successful operation of an injector depends upon the steam pressure, height of lift and temperature of the feed water, and the proper combination of these conditions must be obtained in any case; therefore, its field of usefulness is somewhat limited. The common form of injector combines two distinct functions, the *lifting* and the *forcing* of the water.

*Principle of Operation.*—Fig. 78 shows in diagram the essential parts of the ordinary injector. Steam is admitted through the nozzle *E* and passes through a second nozzle *F*. The friction between the rapidly moving jet of steam and the air lying between

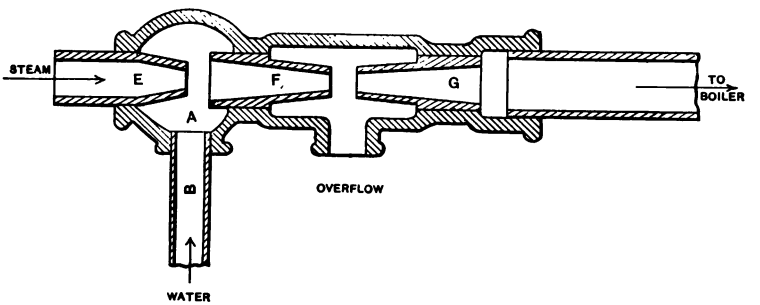



**Fig. 78. Diagram of an Injector.**

it and the sides of the nozzle *F* causes some of the air to be dragged along, thus producing a reduction of pressure in the

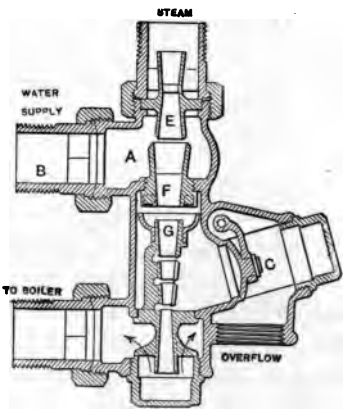



**Fig. 79. Lunkenheimer Injector.**

chamber *A*. A partial vacuum being formed in the suction pipe *B*, water is drawn into the injector and thus the first part of its operation is accomplished. The second part, that is, the forcing

action, may be explained as follows: The jet of steam issuing from the steam nozzle *E* is condensed by the surrounding water and much reduced in size, while its momentum remains the same. This being the fact it is able to enter a much smaller opening than that from which it issued, thereby correspondingly increasing the pressure per square inch of section required to stop it. This increase in pressure is so great that the jet not only has sufficient energy to reënter the boiler against its own pressure, but has enough surplus energy to carry in with it a certain amount of feed water.

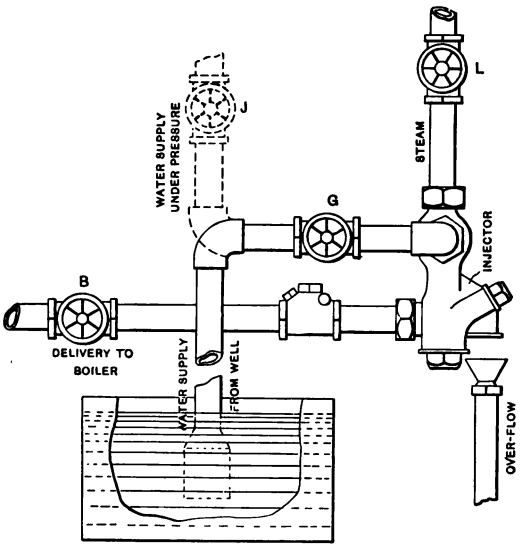



**Fig. 80. Connections for Lunkenheimer Injector.**

Referring again to Fig. 78, the steam enters the nozzle *E* and flows through the combining or mixing tube *F*, and is discharged through the overflow. This action soon exhausts the air from the interior of the injector, as already described, and water is drawn up through the suction pipe and discharged through the overflow with the condensed steam. As soon as the water supply has been cut down to the right amount the strength of the jet becomes sufficient to force its way into the boiler through the discharge or delivery pipe *G*. If the injector were made as

shown in Fig. 78 there would be a constant dripping from the overflow, because the jet would never be of exactly the right size to enter the tube *G* without spattering more or less water from the edges of the opening. This is avoided in practice by making the overflow opening at the top and providing it with a light check valve which prevents the dripping of water when in use, and yet offers but little resistance when first starting the injector. Injectors of this type are called automatic, because they will re-establish the jet entering the boiler after it has been temporarily interrupted from any cause.

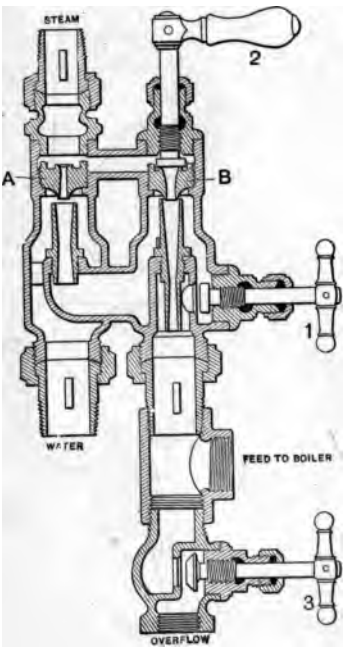



**Fig. 81. Hancock Inspirator.**

*Types of Injectors.*—Fig. 79 shows a section through the Lunkenheimer automatic injector, the corresponding parts being lettered the same as in Fig. 78. The check valve mentioned above is shown at *C*. The method of making the pipe connections for an injector of this type is indicated in Fig. 80.

These injectors are started by opening the valves *B*, *J* and *L* in succession. If the water is taken from a well, the valve *G* in the suction may remain open if the boiler is fed at frequent intervals.

Non-automatic injectors have the overflow closed by a valve instead of a check, which has to be operated by hand in starting and stopping. The Hancock inspirator shown in Fig. 81 is of this type, having a lifting jet *A* and a forcing jet *B*. To start the inspirator, open the overflow valves 1 and 3 and close the forcing steam valve 2. Then open the starting valve in the steam pipe. This puts the lifting jet in operation, the water being discharged

through the overflow. Next close valve 1, and open 2 a quarter turn and close 3. This admits steam through the forcing jet *B*, and, the overflow valves being closed, the water is fed into the boiler. Table XLIII. gives the capacities of this type of injector for different sizes.

## TABLE XLIII.*

CAPACITIES OF HANCOCK INSPIRATOR AND SIZES OF PIPE CONNECTIONS.

| Size (number) | Capacities per hour: With 60 lb. steam pressure and 4 ft. lift | Capacities per hour: Maximum horse power | Pipe connections: Steam | Pipe connections: Suction | Pipe connections: Delivery | Pipe connections: Overflow |
|---|---|---|---|---|---|---|
| 7½ | 60 gals. | 8 | ⅜ | ⅜ | ⅜ | ¼ |
| 8¾ | 90 " | 12 | ⅜ | ½ | ½ | ⅜ |
| 10 | 120 " | 16 | ⅜ | ½ | ½ | ⅜ |
| 12½ | 220 " | 30 | ½ | ¾ | ¾ | ½ |
| 15 | 300 " | 40 | ½ | ¾ | ¾ | ½ |
| 17½ | 420 " | 56 | ¾ | 1 | 1 | ¾ |
| 20 | 540 " | 72 | ¾ | 1 | 1 | ¾ |
| 22½ | 720 " | 96 | 1 | 1¼ | 1¼ | 1 |
| 25 | 900 " | 120 | 1 | 1¼ | 1¼ | 1 |
| 30 | 1,260 " | 168 | 1¼ | 1½ | 1¼ | 1¼ |
| 35 | 1,740 " | 230 | 1¼ | 1½ | 1½ | 1¼ |
| 40 | 2,230 " | 298 | 1½ | 2 | 2 | 1½ |
| 45 | 2,820 " | 376 | 1½ | 2 | 2 | 1½ |
| 50 | 3,480 " | 464 | 2 | 2½ | 2½ | 2 |
| 55 | 3,650 " | 600 | 2 | 2½ | 2½ | 2 |

## TABLE XLIV.*

RANGE OF HANCOCK INSPIRATORS.

| Lift | Minimum steam pressure: Feed-water cold | Minimum steam pressure: Feed-water at 100 degrees F. |
|---|---|---|
| 5 feet | 15 pounds | 15 pounds |
| 10 " | 20 " | 30 " |
| 15 " | 25 " | 40 " |
| 20 " | 35 " | 45 " |
| 25 " | 45 " | 50 " |

* From the catalogue of the Hancock Inspirator Co.

The range of the "Stationary" type of Hancock inspirator under different conditions is given above in Table XLIV. These figures are for the regular patterns. Special inspirators are made which will operate on less than 15 pounds pressure. When used on a short lift they will take feed water up to 150° F. with steam pressures from 80 to 150 pounds.

There are many reliable makes of injectors upon the market, both of the automatic and non-automatic type. Those described above have been taken as simple forms well adapted to illustrate

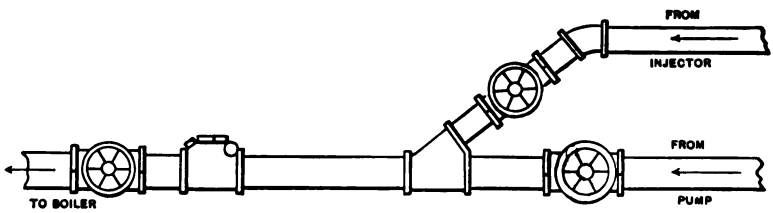



Fig. 82. Connecting Injector with Feed Pipe.

the principles upon which they operate. Fig. 82 shows the method of connecting an injector into the discharge pipe from a feed pump.

### Damper Regulators.

*Diaphragm Regulator.*—Every heating and power plant should be provided with automatic means for closing the dampers when the steam pressure reaches a certain point, and for opening them again when the pressure drops. There are various regulators designed for this purpose, the simplest of which is shown in Fig. 83.

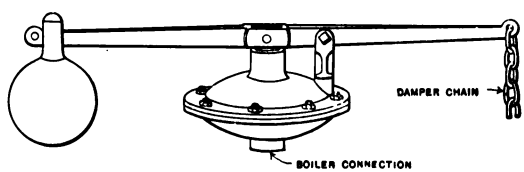



Fig. 83. Damper Regulator for Low-Pressure Boiler.

This consists of a rubber diaphragm enclosed in a cast-iron casing, with the space beneath the diaphragm connected with the boiler pressure. The top of the diaphragm presses against a plate attached by means of a spindle to a hinged lever as shown. One end of the lever has a sliding weight for adjusting it to the pressure at which it is desired to have the regulator operate, while the other end is attached by means of a chain to the damper.

As the pressure in the boiler rises, the diaphragm is forced upward, thus lowering the chain and allowing the damper to close. The connection between the boiler and the regulator should contain a loop or siphon, so that the space beneath the diaphragm

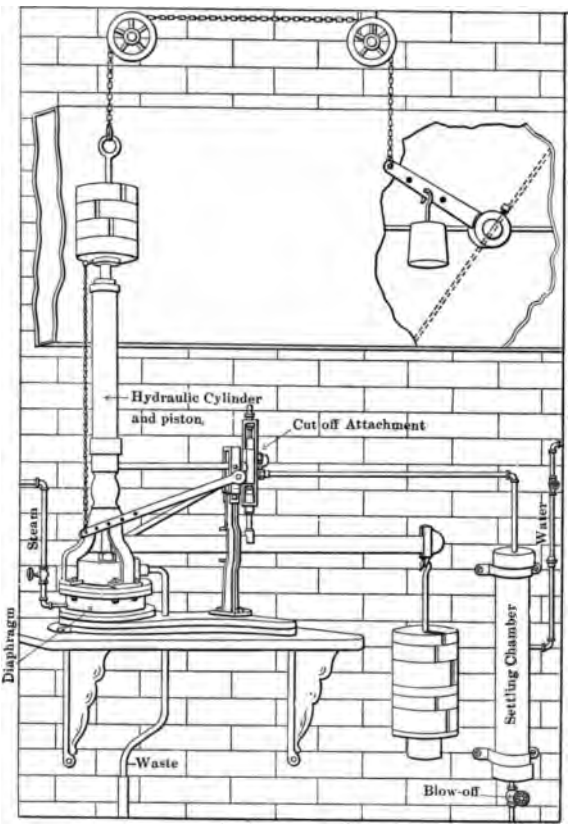



**Fig. 84. Locke Hydraulic Regulator.**

will stand full of water and thus prevent overheating the rubber by the admission of steam. This type of regulator is used only on small low-pressure heating boilers.

*Hydraulic Regulators.*—For power work and other cases where a close and reliable regulation is required, hydraulic

regulators are used. The Locke, shown in Fig. 84, illustrates the general principles upon which this type of regulator operates. In this case the steam pressure is admitted beneath a metal diaphragm which is so weighted as to rise at the pressure it is desired to carry on the boiler. This movement of the diaphragm operates a lever which in turn opens a small valve and admits water pressure beneath a piston. The rising of the piston closes the damper by means of a chain and pulley attachment as indicated. A special cut-off arrangement is provided by means of which the damper may be made to take any intermediate position necessary to give the right amount of draft to maintain an even pressure.

There are several regulators operating upon the same general principle although differing more or less in form and construction.

### Blow-off Arrangement.

*Blow-off Tanks.*—Where the blow-off from a boiler discharges into a sewer, some means must be employed for cooling the water or else the joints of the sewer pipe will be injured. This is accomplished by first passing the water through a special chamber or receiver, called a blow-off tank, one form of which is shown in Fig. 85. This consists of a cast iron receiver *A*, connected with the boiler through the blow-off pipe *B*. The tank ordinarily stands full of cold water.

When hot water is admitted from the boiler, any steam which is formed will be carried off through the vapor pipe *C*, which should extend through the roof of the boiler house. As the hot water enters the top of the tank, the cold water will be forced out from the lower part through the discharge pipe *D*, which connects with the sewer. A small cross-connection *E* is provided for admitting air pressure to the discharge pipe to break the siphon effect and prevent the tank from being drained after the valve in the pipe *B* is closed. This form of tank is usually sunk in the ground so its top is flush with the boiler-room floor, or slightly above it.

Fig. 86 shows a tank of boiler iron made to rest on cast-iron cradles or brick piers. The reference letters in this case indi-

cate the same parts as in Fig. 85. There are in addition a pipe *F* for draining the tank, and a cross-connection *G* for use when the bottom of the boiler is lower than the top of the tank. A manhole should be placed in the shell on top, and a handhole in each end.

Tanks of this description are usually made of iron or steel one-fourth inch thick with single riveted joints.

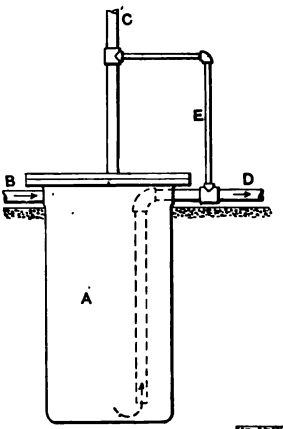



Fig. 85.

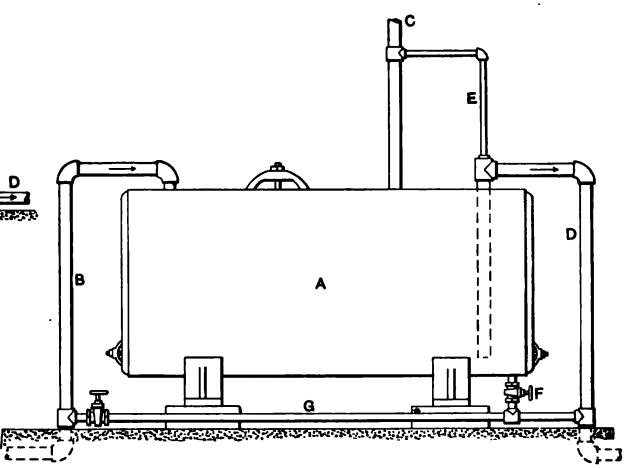



Fig. 86.

Blow Off Tanks.

The size of the blow-off tank depends upon the amount of water it is desired to remove from the boiler at one time. It is customary to blow off a small quantity at frequent intervals, and for this purpose it is usually found sufficient to make the capacity of the tank about one twenty-fourth that of the total volume of the boiler, neglecting the tubes. If there are two boilers, the tank should be made twice as large as for one, or two tanks may be used in series. This holds true up to the maximum number of boilers it is desired to blow off at one time. In a battery of several boilers they would probably be blown off in sections of two or three, and the tank may be proportioned accordingly.

*Arrangement of Blow-off Pipe.*—The blow-off pipe is tapped into the lowest point at the rear end of the boiler or into the mud drum in special forms. A gate valve and asbestos packed

cock are connected into the pipe, outside of the setting, the valve being placed next to the boiler. Special blow-off valves, described in a later chapter, are often substituted for the cock in high pressure work.

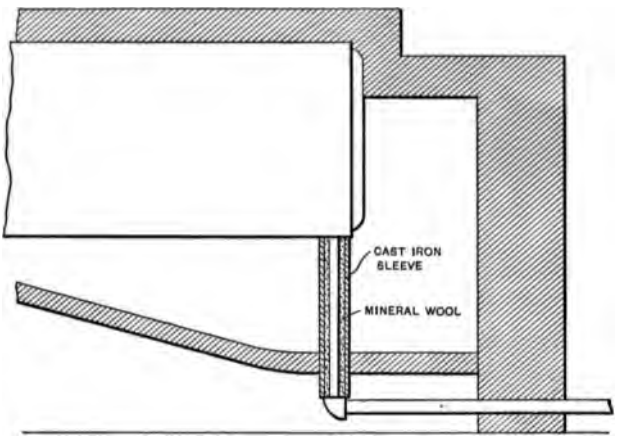



**Fig. 87. Arrangement of Blow-Off Pipe.**

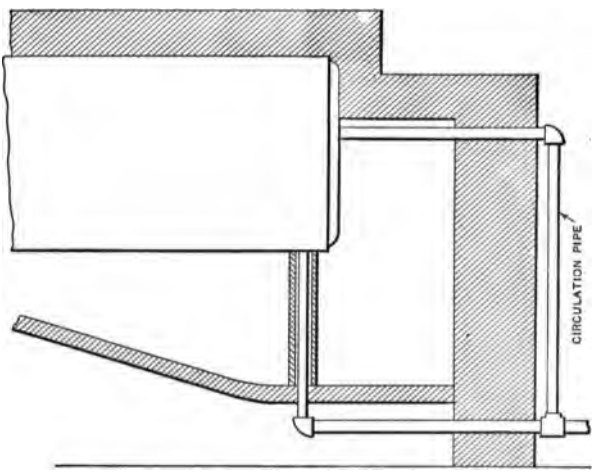



**Fig. 88. Blow Off with Circulation Pipe.**

Different methods are used for protecting the blow-off pipe where it is exposed to the fire in the combustion chamber. In

most water-tube boilers it is located well away from the hottest part of the fire, so that it is only necessary to consider here the blow-off pipe of a tubular boiler. If the blow-off and connections are exposed directly to the hot gases as they pass over the bridge wall they are liable to become overheated and give way. This is especially the case with power boilers where there is no circulation through the pipe. With heating boilers where the returns are brought back through the blow-off pipe a circulation is set up which greatly lessens this danger.

Fig. 87 shows a good arrangement in which the pipe is carried down through the paving and then outside the setting as indicated. The part exposed to the fire is encased in a split cast-iron sleeve held in place by special clamps and bolts. The space between the pipe and sleeve should be packed with some non-conducting material like asbestos or mineral wool. The arrangement shown in Fig. 88 has a circulation pipe which keeps up a movement of the water and thus prevents overheating. Still further protection may be provided in this case by placing cast-iron sleeves upon the exposed pipes as in Fig. 87.

TABLE XLV.

SIZES OF BLOW-OFF CONNECTIONS FOR TUBULAR BOILERS.

| Diameter of boiler | Size of blow-off pipe | Size of pipe for gravity return |
|---|---|---|
| In. | In. | In. |
| 36 | 1¼ | 1½ |
| 42 | 1½ | 2 |
| 48 | 1½ | 2 |
| 54 | 2 | 2½ |
| 60 | 2 | 2½ |
| 66 | 2½ | 3 |
| 72 | 2½ | 3 |

Table XLV. gives suitable sizes of blow-off connections for boilers of different diameters. When the pipe acts also as a gravity return for the condensation from a heating system it is commonly made a size larger.

## CHAPTER XII.

### PIPE AND FITTINGS.

*Wrought-Iron Pipe.*—Wrought-iron pipe is made "standard weight," "extra strong" and "double extra strong." The standard weight is commonly used for all pressures up to 125 pounds per square inch. The heavier weights are often used for higher pressures, although exhaustive tests made by manufacturers seem to show that standard weight pipe is sufficiently strong for all pressures used in ordinary power work at the present time.

When particularly exposed to corrosion, it is well to use extra heavy pipe. This applies to feed lines, sealed returns, underground drip piping, etc., and all lines that are to be run in places which are not easily accessible.

Nearly all of what is commonly known as wrought-iron pipe is in reality wrought steel. There seems to be no especial advantage in using iron in place of a good quality of steel, although some engineers prefer the former.

Wrought-iron pipe is not carried in stock to any great extent, and if it is to be used in any considerable quantity should be ordered well in advance of the time it is to be used.

Table XLVI. gives the dimensions of standard wrought-iron pipe.

The outside diameter of the extra strong and double extra strong pipe is the same as that of the standard weight, the extra thickness being added to the inside. This makes it possible to use the same fittings with any weight of pipe.

*Brass and Copper Pipe.*—Seamless drawn brass and copper tubing may be had in sizes corresponding to standard wrought iron pipe.

This material is used for hot-water service, for connections between feed pumps and boilers, for the attachment of boiler trimmings, and for steam-heating coils in hot-water boilers. It is more durable than iron pipe when in contact with hot water, and its freedom from rust makes it especially adapted for hot water service in connection with laundry and similar work.

*Tin Lined Pipe.*—For long lines of water piping where the expense of brass piping would be too great, iron pipe lined with an alloy of tin and lead is often used. This kind of piping is especially adapted for use in chemical works, where a lead lining is used in place of the alloy.

## TABLE XLVI.*

### DIMENSIONS OF STANDARD WROUGHT-IRON PIPE.

¼ and smaller proved to 300 pounds per square inch by hydraulic pressure.
1¼ and larger proved to 500 pounds per square inch by hydraulic pressure.

| Nominal diameter | Actual outside diameter | Actual inside diameter | Inside circumference | Outside circumference | Length of pipe per square foot of inside surface | Length of pipe per square foot of outside surface | Inside area | Outside area | Length of pipe containing one cubic foot | Weight per foot |
|---|---|---|---|---|---|---|---|---|---|---|
| In. | In. | In. | In. | In. | Ft. | Ft. | In. | In. | Ft. | Lb. |
| ⅛ | 0.405 | 0.270 | 0.848 | 1.272 | 14.15 | 9.44 | 0.0572 | 0.129 | 2500. | 0.243 |
| ¼ | 0.54 | 0.364 | 1.144 | 1.696 | 10.50 | 7.075 | 0.1041 | 0.229 | 1385. | 0.422 |
| ⅜ | 0.675 | 0.494 | 1.552 | 2.121 | 7.67 | 5.657 | 0.1916 | 0.358 | 751.5 | 0.561 |
| ½ | 0.84 | 0.623 | 1.957 | 2.652 | 6.13 | 4.502 | 0.3048 | 0.554 | 472.4 | 0.845 |
| ¾ | 1.05 | 0.824 | 2.589 | 3.299 | 4.635 | 3.637 | 0.5333 | 0.866 | 270. | 1.126 |
| 1 | 1.315 | 1.048 | 3.292 | 4.134 | 3.679 | 2.903 | 0.8627 | 1.357 | 166.9 | 1.670 |
| 1¼ | 1.66 | 1.380 | 4.335 | 5.215 | 2.768 | 2.301 | 1.496 | 2.164 | 96.25 | 2.258 |
| 1½ | 1.90 | 1.611 | 5.061 | 5.969 | 2.371 | 2.01 | 2.038 | 2.835 | 70.65 | 2.694 |
| 2 | 2.375 | 2.067 | 6.494 | 7.461 | 1.848 | 1.611 | 3.355 | 4.430 | 42.36 | 3.600 |
| 2½ | 2.875 | 2.468 | 7.754 | 9.032 | 1.547 | 1.328 | 4.783 | 6.491 | 30.11 | 5.773 |
| 3 | 3.50 | 3.067 | 9.636 | 10.996 | 1.245 | 1.091 | 7.388 | 9.621 | 19.49 | 7.547 |
| 3½ | 4.00 | 3.548 | 11.146 | 12.566 | 1.077 | 0.955 | 9.887 | 12.566 | 14.56 | 9.055 |
| 4 | 4.50 | 4.026 | 12.648 | 14.137 | 0.949 | 0.849 | 12.730 | 15.904 | 11.31 | 10.66 |
| 4½ | 5.00 | 4.508 | 14.153 | 15.708 | 0.848 | 0.765 | 15.939 | 19.635 | 9.03 | 12.34 |
| 5 | 5.563 | 5.045 | 15.849 | 17.475 | 0.757 | 0.629 | 19.990 | 24.299 | 7.20 | 14.50 |
| 6 | 6.625 | 6.065 | 19.054 | 20.813 | 0.63 | 0.577 | 28.889 | 34.471 | 4.98 | 18.767 |
| 7 | 7.625 | 7.023 | 22.063 | 23.954 | 0.544 | 0.595 | 38.737 | 45.663 | 3.72 | 23.27 |
| 8 | 8.625 | 7.982 | 25.076 | 27.096 | 0.478 | 0.444 | 50.039 | 58.426 | 2.88 | 28.177 |
| 9 | 9.625 | 9.001 | 28.277 | 30.433 | 0.425 | 0.394 | 63.633 | 73.715 | 2.26 | 33.70 |
| 10 | 10.75 | 10.019 | 31.475 | 33.772 | 0.381 | 0.355 | 78.838 | 90.762 | 1.80 | 40.06 |
| 11 | 12.00 | 11.25 | 35.343 | 37.699 | 0.340 | 0.318 | 98.942 | 113.097 | 1.455 | 45.95 |
| 12 | 12.75 | 12.000 | 38.264 | 40.840 | 0.313 | 0.293 | 116.535 | 132.732 | 1.235 | 48.98 |
| 14 | 14.00 | 13.25 | 41.268 | 43.982 | 0.290 | 0.273 | 134.582 | 153.938 | 1.069 | 53.92 |
| 15 | 15.00 | 14.25 | 44.271 | 47.124 | 0.271 | 0.254 | 155.968 | 176.715 | .923 | 57.80 |
| 16 | 16.00 | 15.25 | 47.274 | 50.265 | 0.254 | 0.238 | 177.867 | 201.062 | .809 | 61.77 |
| 18 | 18.00 | 17.25 | 53.281 | 56.548 | 0.225 | 0.212 | 225.907 | 254.469 | .638 | 69.66 |
| 20 | 20.00 | 19.25 | 59.288 | 62.832 | 0.202 | 0.191 | 279.720 | 314.160 | .515 | 77.57 |

* From catalogue of Walworth Manufacturing Company.

*Spiral Riveted Pipe.*—Spiral riveted galvanized iron pipe is quite frequently used for exhaust lines and low-pressure heating mains of large size. It has the advantage of lightness, and is lower in cost than standard wrought-iron pipe. It is made up

# TABLE XLVII.

## WEIGHT AND STRENGTH OF SPIRAL RIVETED PIPE.

| Inside Diameter in inches | THICKNESS BIRMINGHAM WIRE GAUGE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No. 20 — 0.035 in. | | No. 18 — 0.049 in. | | No. 16 — 0.065 in. | | No. 14 — 0.083 in. | | No. 12 — 0.109 in. | |
| | Approximate pounds | | Approximate pounds | | Approximate pounds | | Approximate pounds | | Approximate pounds | |
| | Weight per linear foot | Bursting pressure per sq. in. | Weight per linear foot | Bursting pressure per sq. in. | Weight per linear foot | Bursting pressure per sq. in. | Weight per linear foot | Bursting pressure per sq. in. | Weight per linear foot | Bursting pressure per sq. in. |
| 3 | 1½ | 900 | 2 | 1300 | | | | | | |
| 4 | 2 | 700 | 2½ | 1000 | 3¼ | 1250 | | | | |
| 5 | 2½ | 550 | 3 | 800 | 4 | 1000 | | | | |
| 6 | 3 | 450 | 3½ | 700 | 5 | 800 | 6 | 1100 | 8 | 1330 |
| 7 | 3½ | 400 | 4 | 600 | 5½ | 700 | 7 | 950 | 9 | 1140 |
| 8 | 3½ | 350 | 4½ | 500 | 6½ | 600 | 8½ | 825 | 10½ | 1000 |
| 9 | 4¼ | 325 | 5¼ | 450 | 7½ | 550 | 9¼ | 750 | 12 | 880 |
| 10 | 5 | 2.5 | 5½ | 400 | 8 | 500 | 10½ | 650 | 13 | 800 |
| 11 | 5½ | 250 | 6¼ | 360 | 8½ | 450 | 11½ | 600 | 14¼ | 725 |
| 12 | 6 | 225 | 7½ | 330 | 10¼ | 400 | 13¼ | 550 | 17 | 660 |
| 13 | 6½ | 210 | 8 | 300 | 11 | 380 | 14½ | 500 | 18 | 615 |
| 14 | 7 | 200 | 9 | 280 | 12 | 360 | 15½ | 470 | 20 | 570 |
| 15 | 7½ | 190 | 9½ | 260 | 13 | 330 | 16½ | 450 | 21½ | 530 |
| 16 | 8 | 160 | 10 | 250 | 13½ | 300 | 18 | 400 | 23¼ | 500 |
| 18 | 9 | 150 | 11¼ | 220 | 15½ | 280 | 20 | 370 | 25½ | 440 |
| 20 | 9½ | 140 | 12½ | 200 | 16½ | 250 | 22 | 325 | 28¼ | 400 |
| 22 | 10½ | 125 | 13½ | 180 | 18¼ | 230 | 24 | 300 | 31 | 365 |
| 24 | 11½ | 110 | 14½ | 160 | 20 | 210 | 26¼ | 275 | 34 | 335 |

with flanged fittings for steam work the same as other kinds of pipe. Fig. 89 shows a section of this pipe and the method of making up the joints for steam and hot-water work. It is commonly made in lengths of 15, 20 and 25 feet.

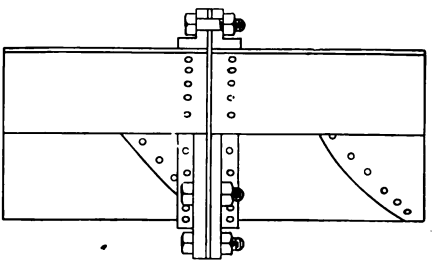


**Fig. 89. Spiral Riveted Pipe.**

Table XLVII., from the catalogue of the American Spiral Pipe Works, gives the weight per foot and the bursting pressure for different thicknesses of material. A factor of safety of at least 4 should be employed when using this pipe for steam or water.

*Equation of Pipes.*—It is frequently desired to know what number of pipes of a given size are equal in carrying capacity to one pipe of a larger size. At the same velocity of flow the volume delivered by two pipes of different sizes is proportional to the squares of their diameters; thus, one 4-inch pipe will deliver the same volume as four 2-inch pipes. With the same head, however, the velocity is less in the smaller pipe, and the volume delivered varies about as the square root of the fifth power. Table XLVIII. on the next page has been calculated on this basis. The figures opposite the intersection of any two sizes is the number of the smaller-sized pipes required to equal one of the larger. Thus, one 4-inch pipe is equal to 5.7 2-inch pipes.

### Pipe Fittings.

Cast-iron fittings, both screwed and flanged, are used for all classes of steam work. These are commonly made in three weights. The lightest for low pressures, such as exhaust or condenser connections; standard weight, for pressures up to 100 or 125 pounds per square inch; and extra heavy for higher pressures up to 250 pounds per square inch.

Fittings are made in a great variety of forms, the most common being the elbow, tee, cross, return bend and coupling, shown in

TABLE XLVIII.*

EQUATION OF PIPES.

| Diameter, inches | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 14 | 16 | 18 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 5.7 | 1 | | | | | | | | | | | | | |
| 3 | 15.6 | 2.8 | | | | | | | | | | | | | |
| 4 | 32 | 5.7 | 2.1 | | | | | | | | | | | | |
| 5 | 55.9 | 9.9 | 3.6 | 1.7 | | | | | | | | | | | |
| 6 | 88.2 | 15.6 | 5.7 | 2.8 | .6 | | | | | | | | | | |
| 7 | 130 | 22.9 | 8.3 | 4. | 2.3 | 1.5 | | | | | | | | | |
| 8 | 181 | 32 | 11.7 | 5.7 | 3.2 | 2.1 | .4 | | | | | | | | |
| 9 | 243 | 43 | 15.6 | 7.6 | .3 | 2.8 | .9 | .3 | 1 | | | | | | |
| 10 | 316 | 55.9 | 20.3 | 9.9 | 5.7 | 3.6 | 2.4 | 1.7 | 1.3 | 1 | | | | | |
| 11 | 401 | 70.9 | 25.7 | 12.5 | .2 | 4.6 | 3.1 | 2.2 | 1. | 1.3 | | | | | |
| 12 | 499 | 88.2 | 32 | 15.6 | 8.9 | 5.7 | 3.8 | 2.8 | 2. | 1.6 | 1 | | | | |
| 13 | 609 | 108 | 39.1 | 19 | 10.9 | 7.1 | 4.7 | 3.4 | 2.5 | 1.9 | 1.2 | | | | |
| 14 | 733 | 130 | 47 | 22.9 | 13.1 | 8.3 | 5.7 | 4 | 3.0 | 2.3 | 1.5 | 1 | | | |
| 15 | 787 | 154 | 55.9 | 27.2 | 15.6 | 9.9 | 6.7 | 4.8 | 3.6 | 2.8 | 1.7 | 1.2 | | | |
| 16 | ..... | 181 | 65.7 | 32 | 18.3 | 11.7 | 7.9 | 5.7 | 4.2 | 3.2 | 2.1 | 1.4 | 1 | | |
| 17 | ..... | 211 | 76.4 | 37.2 | 21.3 | 13.5 | 9.2 | 6.6 | 4. | 3.8 | 2.4 | 1.6 | 1.2 | | |
| 18 | ..... | 243 | 88.2 | 43 | 24.6 | 15.6 | 10.6 | 7.6 | 5.7 | 4.3 | 2.8 | 1.9 | 1.3 | 1 | |
| 19 | ..... | 278 | 101 | 49.1 | 28.1 | 17.8 | 12.1 | 8.7 | 6.5 | 5 | 3.2 | 2.1 | 1.5 | 1.1 | |
| 20 | ..... | 316 | 115 | 55.9 | 32 | 20.3 | 13.8 | 9.9 | 7.4 | 5.7 | 3.6 | 2.4 | 1.7 | 1.3 | 1 |

*From the catalogue of the Walworth Manufacturing Company.

Fig. 90, *A* to *E* inclusive. At *F* is an eccentric reducing coupling for use when connections are made in the side or top of a long run of pipe, which reduces in size as the branches are taken off.

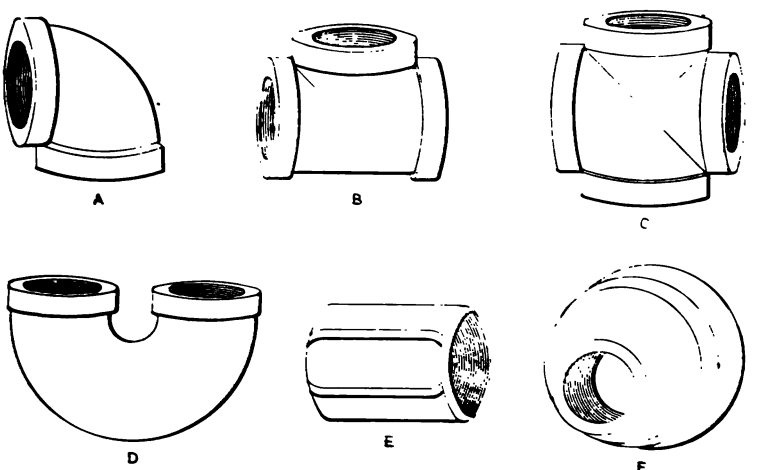



Fig. 90. Pipe Fittings.

By the use of this fitting the bottom of the main is kept level and pockets for the collection of water are avoided.

Various modifications of these fittings may be had to meet almost any condition which may arise in designing a system of piping.

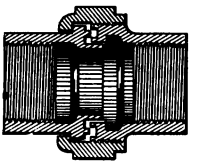


Fig. 91. Union.

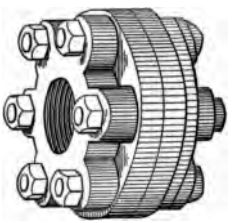


Fig. 92. Flange Joint.

Elbows of 45 degrees are used for making an eighth turn, and Y branches for making a 45-degree connection with a main.

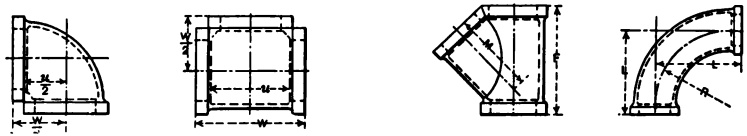
When pipes are to be joined permanently, couplings are commonly used, but if it is desired to make any part of the work removable, unions are employed instead. All steam and water connections with boilers, engines, pumps and other apparatus should be made up with unions. For small pipes, the screwed brass union shown in Fig. 91 is used, but for larger sizes, over 2 or 2½ inches, cast-iron flanges are screwed to the ends of the pipe and then bolted together as indicated in Fig. 92.

Dimensions of standard weight Walworth fittings of common form are given in the tables on the two following pages, and will be found useful in laying out piping where the available space is limited. It should be remembered, however, that the fittings made by different manufacturers vary slightly, and if any particular make is to be used the exact dimensions should be taken from a catalogue.

*Pipe Bends.*—Pipe bends of various forms are commonly used in making connections about boilers and engines for taking the strains due to expansion. Connections made up in this way are less rigid than when straight lengths of pipe and cast-iron fittings are used. Pipe bends are often employed in hot-water or steam work where it is desired to reduce the friction in the pipe to the smallest amount.

# TABLE XLIX.

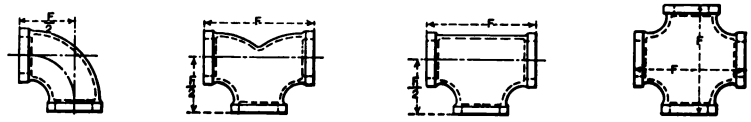
## DIMENSIONS OF SCREWED FITTINGS.



The first two illustrations apply to the first part of the table and the last two to the second part.

| Pipe size, inches | | $\frac{1}{4}$ | | | | | | 2 | $2\frac{1}{2}$ | 3 | $3\frac{1}{2}$ | 4 | $4\frac{1}{2}$ | 5 | 6 | 7 | 8 | 9 | 10 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Face to face, inches | W | $1\frac{1}{2}$ | $\frac{33}{32}$ | $2\frac{5}{16}$ | $2\frac{5}{8}$ | $3\frac{1}{16}$ | $3\frac{5}{8}$ | | $4\frac{3}{4}$ | $5\frac{3}{4}$ | $6\frac{5}{8}$ | $7\frac{5}{16}$ | $8\frac{1}{16}$ | $8\frac{13}{16}$ | $9\frac{5}{16}$ | $10\frac{3}{8}$ | $12\frac{1}{16}$ | $13\frac{7}{16}$ | 15 | $16\frac{1}{2}$ | $19\frac{1}{16}$ |
| Center to face, inches | $\frac{w}{2}$ | $\frac{3}{4}$ | $\frac{57}{64}$ | $\frac{3}{32}$ | $\frac{5}{16}$ | $1\frac{17}{32}$ | | 2 | $2\frac{3}{8}$ | $2\frac{7}{8}$ | $3\frac{5}{16}$ | $3\frac{11}{32}$ | $4\frac{1}{32}$ | $4\frac{13}{32}$ | $4\frac{21}{32}$ | $5\frac{5}{16}$ | $6\frac{1}{16}$ | $6\frac{13}{16}$ | $7\frac{1}{2}$ | $8\frac{1}{4}$ | $9\frac{5}{16}$ |
| Thread to thread, inches | u | $\frac{3}{4}$ | $1\frac{5}{32}$ | $\frac{5}{16}$ | | $1\frac{13}{32}$ | $2\frac{1}{4}$ | $2\frac{3}{32}$ | 3 | $3\frac{3}{4}$ | $4\frac{5}{8}$ | $5\frac{5}{16}$ | $5\frac{13}{16}$ | $6\frac{5}{16}$ | $6\frac{13}{16}$ | $7\frac{5}{8}$ | $9\frac{1}{4}$ | $10\frac{3}{8}$ | $11\frac{1}{2}$ | 13 | $15\frac{3}{32}$ |

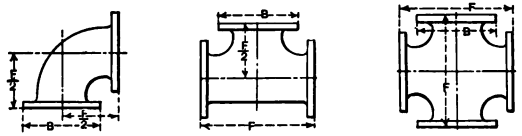
| Pipe size, inches | | $\frac{3}{4}$ | | $1\frac{1}{4}$ | | | $2\frac{1}{2}$ | | $3\frac{1}{2}$ | 4 | $4\frac{1}{2}$ | 5 | 6 | 7 | 8 | 9 | 10 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Face to face, inches | F | $2\frac{3}{4}$ | $3\frac{1}{2}$ | $3\frac{3}{4}$ | $4\frac{3}{4}$ | $5\frac{1}{2}$ | $6\frac{3}{4}$ | $7\frac{5}{8}$ | $8\frac{3}{4}$ | $9\frac{3}{4}$ | $10\frac{1}{2}$ | | 13 | $14\frac{3}{4}$ | 17 | 19 | $20\frac{3}{4}$ | $24\frac{1}{2}$ |
| Center to face, inches | M | $2\frac{1}{16}$ | $2\frac{7}{16}$ | $2\frac{1}{2}$ | $3\frac{1}{4}$ | | 5 | $5\frac{3}{4}$ | $6\frac{1}{2}$ | $7\frac{1}{4}$ | $7\frac{7}{8}$ | $8\frac{1}{2}$ | $9\frac{3}{4}$ | $11\frac{1}{4}$ | $13\frac{1}{2}$ | $14\frac{1}{2}$ | $15\frac{7}{8}$ | 19 |
| Center to face, inches | L | $2\frac{3}{4}$ | $3\frac{1}{16}$ | $3\frac{3}{4}$ | 4 | $5\frac{1}{2}$ | $6\frac{1}{4}$ | $7\frac{1}{2}$ | $8\frac{1}{2}$ | $10\frac{3}{4}$ | $10\frac{5}{8}$ | | 13 | $14\frac{1}{2}$ | $18\frac{1}{4}$ | $21\frac{1}{2}$ | $24\frac{7}{8}$ | 31 |
| Radius of center, inches | R | $2\frac{1}{4}$ | $2\frac{1}{2}$ | $2\frac{3}{4}$ | $3\frac{3}{4}$ | $4\frac{7}{8}$ | $5\frac{1}{4}$ | $5\frac{5}{8}$ | $6\frac{3}{4}$ | $9\frac{1}{4}$ | $9\frac{1}{4}$ | $9\frac{1}{2}$ | $11\frac{3}{4}$ | $12\frac{3}{4}$ | $16\frac{1}{2}$ | $19\frac{3}{4}$ | $22\frac{7}{8}$ | $28\frac{3}{4}$ |



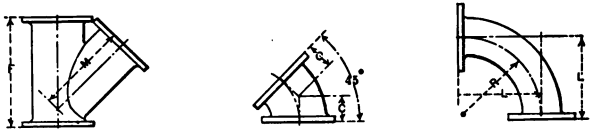
| Pipe size, inches | | $\frac{3}{4}$ | 1 | $1\frac{1}{4}$ | $1\frac{1}{2}$ | 2 | $2\frac{1}{2}$ | 3 | $3\frac{1}{2}$ | 4 | $4\frac{1}{2}$ | 5 | 6 | 7 | 8 | 9 | 10 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Face to face, inches | F | 4 | $4\frac{1}{2}$ | $5\frac{1}{4}$ | 6 | $7\frac{1}{8}$ | $9\frac{1}{2}$ | 11 | $11\frac{1}{2}$ | 12 | $12\frac{1}{2}$ | 14 | 15 | $17\frac{3}{4}$ | 19 | $21\frac{1}{2}$ | 23 | $25\frac{1}{4}$ |
| Center to face, inches | $\frac{F}{2}$ | 2 | $2\frac{1}{4}$ | $2\frac{5}{8}$ | 3 | $3\frac{5}{8}$ | $4\frac{3}{4}$ | $5\frac{1}{2}$ | $5\frac{3}{4}$ | 6 | $6\frac{1}{4}$ | 7 | $7\frac{1}{2}$ | $8\frac{7}{8}$ | $9\frac{1}{2}$ | $10\frac{3}{4}$ | $11\frac{1}{4}$ | $12\frac{3}{4}$ |

# TABLE L.

## DIMENSIONS OF FLANGED FITTINGS.



| Size wrought iron pipe, inches.. | | 2½ | 3 | 3½ | 4 | 4½ | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 14 | 15 | 16 | 17 | 18 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Face to face, inches..... | F | 9½ | 11 | 11½ | 12 | 12½ | 14 | 15 | 17⅜ | 19 | 21½ | 23 | 25½ | 28 | 28 | 29½ | 30½ | 33 | 36 |
| Center to face, inches..... | F/2 | 4¾ | 5½ | 5¾ | 6 | 6¼ | 7 | 7½ | 8⅝ | 9½ | 10¾ | 11½ | 12¾ | 14 | 14 | 14⅝ | 15¼ | 16½ | 18 |
| Diameter of flanges, inches..... | B | 7 | 7½ | 8½ | 9 | 9½ | 10 | 11 | 12½ | 13½ | 15 | 16 | 19 | 20 | 21 | 22½ | 23½ | 25 | 27½ |
| Thickness of flanges, inches..... | | 1/16 | 3/16 | 3/16 | 5/16 | 5/16 | 5/16 | 1 | 1 1/16 | 1 1/16 | 1 1/16 | 1 3/16 | 1¼ | 1⅜ | 1⅜ | 1⅜ | 1 7/16 | 1 9/16 | 1 11/16 |
| Diameter of bolt circle, inches.. | | 5½ | 6 | 7 | 7¼ | 7¾ | 8½ | 9½ | 10¾ | 11¾ | 13¼ | 14¼ | 17 | 18 | 18¾ | 20 | 21½ | 22¾ | 25 |
| Number of bolts..... | | 4 | 4 | 4 | 8 | 8 | 8 | 8 | 8 | 8 | 12 | 12 | 12 | 12 | 12 | 16 | 16 | 16 | 20 |
| Size of bolts, inches..... | | ½ | ½ | ½ | ½ | ⅝ | ⅝ | ⅝ | ⅝ | ⅝ | ⅝ | ¾ | ¾ | ⅞ | ⅞ | ⅞ | ⅞ | 1 | 1 |



| Size wrought iron pipe, inches.. | | 2½ | 3 | 3½ | 4 | 4½ | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 14 | 15 | 16 | 17 | 18 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Face to face, inches..... | F | 10½ | 12 | 12½ | 14 | 14½ | 15½ | 16½ | 19 | 21⅜ | 22½ | 24½ | 28½ | 31½ | 31½ | 33½ | 35½ | 38 | 41½ |
| Center to face, inches..... | M | 9 | 10½ | 10⅞ | 11¾ | 12 | 13 | 14½ | 15⅝ | 17½ | 19½ | 20½ | 24½ | 26⅝ | 26⅝ | 28⅝ | 30½ | 32 | 33 |
| Center to face, inches..... | C | 2¾ | 3¼ | 3⅜ | 3½ | 3⅝ | 3⅞ | 4⅜ | 5 | 5½ | 5½ | 5⅝ | 6½ | 7 | 7 | 7½ | 7⅝ | 7¾ | 9 |
| Center to face, inches..... | L | 6½ | 7½ | 8¼ | 19⅝ | 10⅞ | 11¾ | 13 | 14½ | 18½ | 21½ | 24¾ | 31 | 33 | 33 | 35 | 36 | 39 | 42 |
| Radius of center, inches... ..... | R | 5¼ | 5⅞ | 6¾ | 9½ | 9¼ | 9¾ | 11⅜ | 12⅝ | 16½ | 19¾ | 22⅞ | 28¾ | 30¾ | 30¾ | 32⅝ | 33½ | 36⅜ | 39¼ |

Fig. 93 shows some of the more common forms. These bends are made to order with a minimum radius equal to 5 diameters of the pipe. From 4 to 6 inches of straight pipe should be allowed at each end next to the flange.

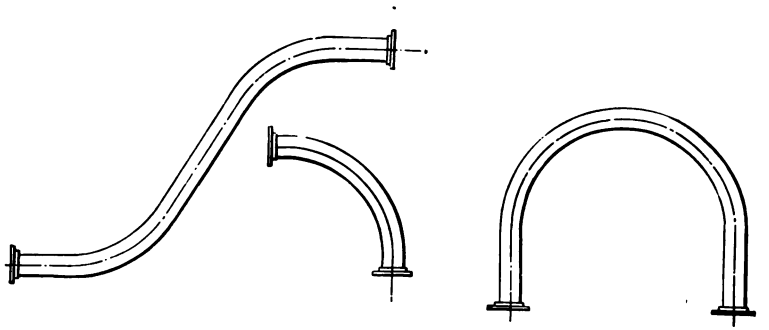


Fig. 93. Pipe Bends.

### Joints, Hangers, Etc.

*Flanged Joints.*—For low steam pressures, the flanges are simply screwed onto the pipe ends, a thin gasket of sheet packing placed between them, and then drawn together with bolts. For

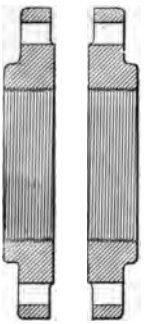


Fig. 94.

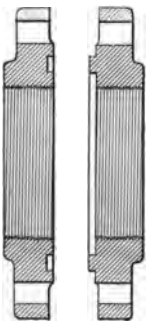


Fig. 95.

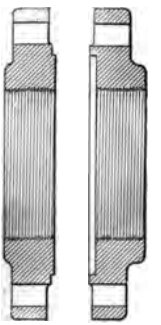


Fig. 96.

higher pressures more care must be taken to make the joints tight and durable. Flanges are commonly made in three ways, as follows: Those with a plain face, Fig. 94; tongue and groove, Fig. 95, and with a raised face inside the bolt holes, Fig. 96.

There are various methods of securing the flange to the pipe in order to make a tight joint. One of the simplest and most satisfactory, considering first cost, ease of repairing, and freedom from leaks, is made by threading the pipe with a full taper, then screwing on the flange by power until the end of the pipe projects about $\frac{1}{16}$ inch, and facing off in a lathe. Another method is to round off the inner edge of the flange and expand or peen over the end of the pipe as shown in Fig. 97 and then face in a lathe

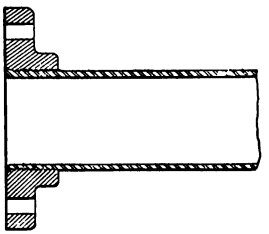


Fig. 97.

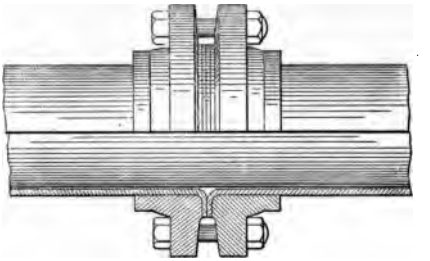


Fig. 98.

as before. Flanges are sometimes shrunk in place, and also riveted. With the latter arrangement the joint is apt to leak after a time around the rivets. Where especially fine work is desired, and the first cost does not prohibit it, wrought-iron pipe may be used with flanges of the same material welded in place. Work of this kind must be done where the pipe is manufactured.

There are several patented joints which give very satisfactory results. That shown in Fig. 98 is made by the Walworth Manufacturing Company. Its construction is evident from the cut and requires no explanation. The principal objection to the tongue and groove joint, and also to the raised face, when the depth of step is too great, is the difficulty of springing apart a line of heavy piping to remove a section, or for repacking a joint.

For uniformity among the different manufacturers of valves and fittings, standard dimensions of flanges have been adopted. Table LI. gives dimensions adopted by the American Society of Mechanical Engineers and Master Steamfitters' Association, and is suitable for pressures up to 125 pounds per square inch.

Table LII., known as the Manufacturers' Standard, is for higher pressures up to 250 pounds per square inch.

*Gaskets.*—For high-pressure piping with faced flanges there is probably nothing better in the way of a gasket than the best quality of corrugated copper. This is usually made small enough to fit inside the bolt circle, although it is sometimes punched for the bolt holes and made the same size as the flange.

TABLE LI.

DIMENSIONS OF FLANGES ADOPTED BY THE A. S. M. E. AND M. S. A.

| Diameter of pipe | Diameter of flange | Thickness of flange | Diameter of bolt circle | Number of bolts | Diameter of bolts, pressure under 80 lb. | Diameter of bolts, pressure over 80 lb. |
|---|---|---|---|---|---|---|
| In. | In | In. | In. | | In. | In. |
| 2 | 6 | $\frac{3}{4}$ | $4\frac{3}{4}$ | 4 | $\frac{1}{2}$ | $\frac{5}{8}$ |
| $2\frac{1}{2}$ | 7 | $\frac{13}{16}$ | $5\frac{1}{2}$ | 4 | $\frac{1}{2}$ | $\frac{5}{8}$ |
| 3 | $7\frac{1}{2}$ | $\frac{13}{16}$ | 6 | 4 | $\frac{1}{2}$ | $\frac{5}{8}$ |
| $3\frac{1}{2}$ | $8\frac{1}{2}$ | $\frac{7}{8}$ | 7 | 4 | $\frac{1}{2}$ | $\frac{5}{8}$ |
| 4 | 9 | $\frac{15}{16}$ | $7\frac{1}{2}$ | 4 | $\frac{5}{8}$ | $\frac{3}{4}$ |
| $4\frac{1}{2}$ | $9\frac{1}{2}$ | $\frac{15}{16}$ | $7\frac{3}{4}$ | 8 | $\frac{5}{8}$ | $\frac{3}{4}$ |
| 5 | 10 | $\frac{15}{16}$ | $8\frac{1}{2}$ | 8 | $\frac{5}{8}$ | $\frac{3}{4}$ |
| 6 | 11 | 1 | $9\frac{1}{2}$ | 8 | $\frac{5}{8}$ | $\frac{3}{4}$ |
| 7 | $12\frac{1}{2}$ | $1\frac{1}{16}$ | $10\frac{3}{4}$ | 8 | $\frac{5}{8}$ | $\frac{3}{4}$ |
| 8 | $13\frac{1}{2}$ | $1\frac{1}{8}$ | $11\frac{3}{4}$ | 8 | $\frac{5}{8}$ | $\frac{3}{4}$ |
| 9 | 15 | $1\frac{1}{8}$ | $13\frac{1}{4}$ | 12 | $\frac{5}{8}$ | $\frac{3}{4}$ |
| 10 | 16 | $1\frac{3}{16}$ | $14\frac{1}{4}$ | 12 | $\frac{3}{4}$ | $\frac{7}{8}$ |
| 12 | 19 | $1\frac{1}{4}$ | 17 | 12 | $\frac{3}{4}$ | $\frac{7}{8}$ |
| 14 | 21 | $1\frac{3}{8}$ | $18\frac{3}{4}$ | 12 | $\frac{7}{8}$ | 1 |
| 15 | $22\frac{1}{4}$ | $1\frac{3}{8}$ | 20 | 16 | $\frac{7}{8}$ | 1 |
| 16 | $23\frac{1}{2}$ | $1\frac{7}{16}$ | $21\frac{1}{4}$ | 16 | $\frac{7}{8}$ | 1 |
| 18 | 25 | $1\frac{5}{8}$ | $22\frac{3}{4}$ | 16 | 1 | $1\frac{1}{8}$ |
| 20 | $27\frac{1}{2}$ | $1\frac{11}{16}$ | 25 | 20 | 1 | $1\frac{1}{8}$ |

There is nothing to be gained, however, by the latter arrangement, and the narrow gasket is now used in the best class of work. This type of gasket can be used both with the plain and raised face flange. Special forms of copper gaskets are also made for the tongue and groove joint.

Sheet packing is made in various grades. The best pure sheet packing is composed of rubber and certain heat-resisting materials properly mixed and vulcanized.

For high-pressure work, with faced flanges, the packing should not be over $\frac{1}{16}$ inch in thickness; for low-pressure work and where the flanges are more or less uneven, it should be about $\frac{1}{8}$ inch in thickness.

There are a number of metallic and semi-metallic packings upon the market, each claiming its own particular advantages.

TABLE LII.

MANUFACTURERS' STANDARD FOR FLANGES.

| Diameter of pipe | Diameter of flange | Thickness of flange | Diameter of bolt circle | Number of bolts | Diameter of bolts |
|---|---|---|---|---|---|
| In. | In. | In. | In. | | In. |
| 2 | $6\frac{1}{2}$ | $\frac{7}{16}$ | 5 | 4 | $\frac{5}{8}$ |
| $2\frac{1}{2}$ | $7\frac{1}{2}$ | 1 | $5\frac{7}{8}$ | 4 | $\frac{3}{4}$ |
| 3 | $8\frac{1}{4}$ | $1\frac{1}{16}$ | $6\frac{5}{8}$ | 8 | $\frac{5}{8}$ |
| $3\frac{1}{2}$ | 9 | $1\frac{3}{16}$ | $7\frac{1}{4}$ | 8 | $\frac{5}{8}$ |
| 4 | 10 | $1\frac{1}{4}$ | $7\frac{7}{8}$ | 8 | $\frac{3}{4}$ |
| $4\frac{1}{2}$ | $10\frac{1}{2}$ | $1\frac{5}{16}$ | $8\frac{1}{2}$ | 8 | $\frac{3}{4}$ |
| 5 | 11 | $1\frac{3}{8}$ | $9\frac{1}{4}$ | 8 | $\frac{3}{4}$ |
| 6 | $12\frac{1}{2}$ | $1\frac{7}{16}$ | $10\frac{5}{8}$ | 12 | $\frac{3}{4}$ |
| 7 | 14 | $1\frac{1}{2}$ | $11\frac{7}{8}$ | 12 | $\frac{7}{8}$ |
| 8 | 15 | $1\frac{5}{8}$ | 13 | 12 | $\frac{7}{8}$ |
| 9 | 16 | $1\frac{3}{4}$ | 14 | 12 | $\frac{7}{8}$ |
| 10 | $17\frac{1}{2}$ | $1\frac{7}{8}$ | $15\frac{1}{4}$ | 16 | $\frac{7}{8}$ |
| 12 | 20 | 2 | $17\frac{3}{4}$ | 16 | $\frac{7}{8}$ |
| 14 | $22\frac{1}{2}$ | $2\frac{1}{8}$ | 20 | 20 | $\frac{7}{8}$ |
| 15 | $23\frac{1}{2}$ | $2\frac{3}{16}$ | 21 | 20 | 1 |
| 16 | 25 | $2\frac{1}{4}$ | $22\frac{1}{2}$ | 20 | 1 |
| 18 | 27 | $2\frac{3}{8}$ | $24\frac{1}{2}$ | 24 | 1 |
| 20 | $29\frac{1}{2}$ | $2\frac{1}{2}$ | $26\frac{3}{4}$ | 24 | $1\frac{1}{8}$ |
| 22 | $31\frac{1}{2}$ | $2\frac{5}{8}$ | $28\frac{3}{4}$ | 28 | $1\frac{1}{8}$ |
| 24 | 34 | $2\frac{3}{4}$ | $31\frac{1}{4}$ | 28 | $1\frac{1}{4}$ |

*Hangers.*—Hangers of various patterns are used for supporting steam and return pipes in overhead positions. When the ceiling construction is of wood they are usually held in place by lag screws, screwed into the beams or joists. When fireproof construction is used, the hangers are either clamped to the lower flanges of the *I*-beams or attached to iron plates embedded in the masonry above the arches. The requirements of a satisfactory hanger are that it shall be adjustable to the proper alignment of

the pipe and have sufficient lateral movement to swing with the expansion of the pipe without straining. Hangers are usually placed from 10 to 12 feet apart on straight runs of pipe, with extra ones at bends or where other special conditions require

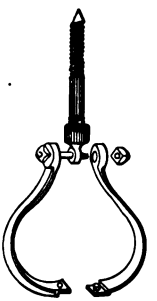


Fig. 99.

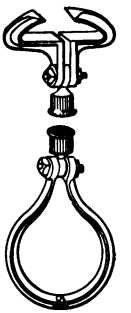


Fig. 100.

Pipe Hangers.

them. Fig. 99 shows an adjustable hanger with lag screw for attaching to a wooden ceiling, while Fig. 100 is provided with a clamp for fastening to an *I*-beam. Where pipes run near the

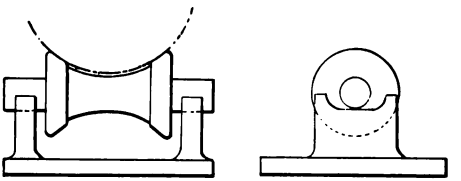


Fig. 101. Pipe Support.

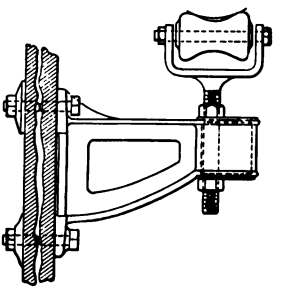


Fig. 102. Pipe Bracket.

floor they are usually supported on rolls which rest in small cast-iron bases screwed or bolted to the floor. (See Fig. 101.)

Fig. 102 shows a similar roll attached to a wall bracket. Where several overhead pipes are run side by side they are often supported upon rolls turning upon rods hung from the ceiling above.

Spring hangers are sometimes employed when piping connecting with high-speed engines is supported from the floor above, in

buildings where vibration is objectionable. In case hangers of this kind are used, some form of safety device should be employed for catching the pipe should the springs give way. The constant vibration of the piping is almost sure to weaken the springs after a time and other means of support for use in case of an emergency should always be provided.

### Pipe Expansion.

The following table shows the expansion of wrought-iron pipes when steam at different pressures is turned into them.

TABLE LIII.

EXPANSION OF WROUGHT-IRON PIPE DUE TO HEAT FROM STEAM.

| Temperature of air when pipes are fitted | Expansion per 100 feet when heated to | | | |
|---|---|---|---|---|
| | 215 degrees, 1 lb. steam pressure | 265 degrees, 25 lb. steam pressure | 297 degrees, 50 lb. steam pressure | 338 degrees, 100 lb. steam pressure |
| 0 degrees | 1.72 inches | 2.12 inches | 2.31 inches | 2.70 inches |
| 32 " | 1.47 " | 1.78 " | 2.12 " | 2.45 " |
| 64 " | 1.21 " | 1.61 " | 1.87 " | 2.19 " |

From the preceding it is evident that in laying out a system of piping care must be taken to provide for this increase in length without producing excessive strains upon the pipe and fittings.

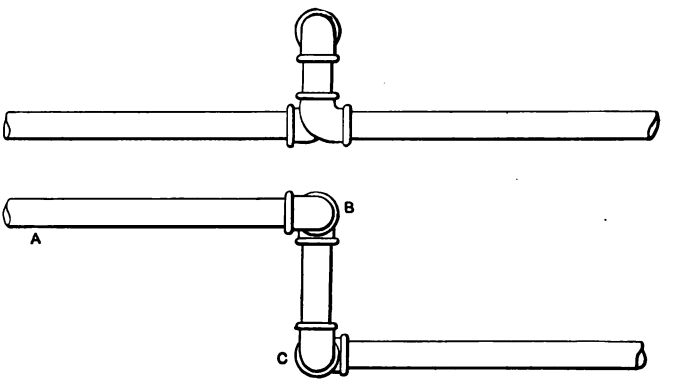



**Fig. 103. Swivel Joint.**

In case of the smaller sizes this may be cared for by means of offsets and bends which allow the pipe to spring or give. For the larger sizes, this simple method will not be sufficient unless the offsets are of considerable length, and swivels or slip joints must be used to take up the expansion.

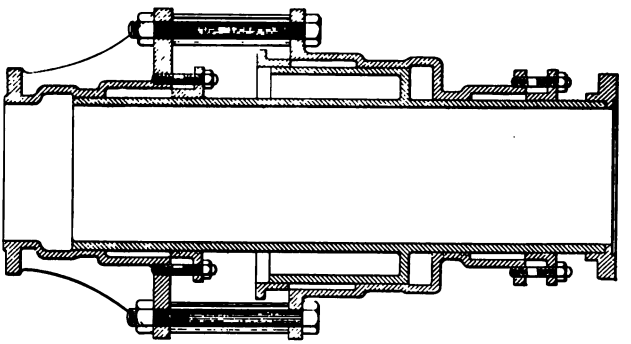


Fig. 104. Balanced Expansion Joint.

*Expansion Joints.*—The method of making up a swivel joint is shown in Fig. 103. Any lengthening of the pipe *A* will be taken up by a slight turning or swivel movement at the points

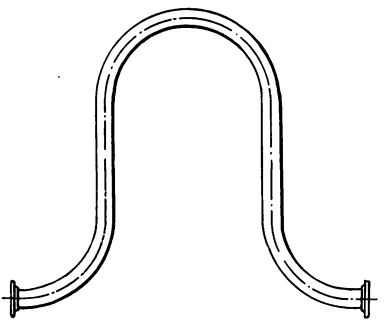


Fig. 105. Expansion Loop.

*B* and *C*. The length of the offset *B C* should be at least 5 feet for each 100 feet length of run. Special joints are also made which may be used in place of the elbows and nipples shown in Fig. 103.

If slip joints are used on high-pressure work they should always be balanced against the steam pressure acting upon the end of the pipe. Fig. 104, taken from *The Engineer,* is an admirable form of balanced expansion joint. It has an enlargement cast on the sleeve, which forms a piston, as shown. In the sleeve below the piston are drilled holes which admit live steam. The area of the piston on which the steam acts must be made equal to the area of the main steam pipe, so that, while permitting free expansion, it is also perfectly balanced.

The expansion loop shown in Fig. 105 is used to some extent for pipes up to 3 or 4 inches in diameter where the amount of expansion is small. Copper was formerly used to quite an extent for loops of this kind, but on account of its low elastic limit, and the liability of flaws in manufacture it has been largely superseded by the best quality of mild steel.

## CHAPTER XIII.

### VALVES.

Among the requirements of a good valve, are, sufficient weight of metal to prevent its being bent or sprung out of shape when connected with the piping; valve seats that are easily repaired or renewed, freedom from pockets or projections which may catch dirt or scale, and arrangements for easily packing the stem or spindle when under pressure.

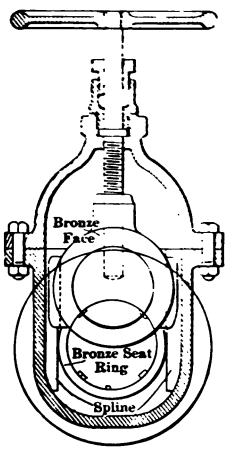



Fig. 106. Inside Screw.

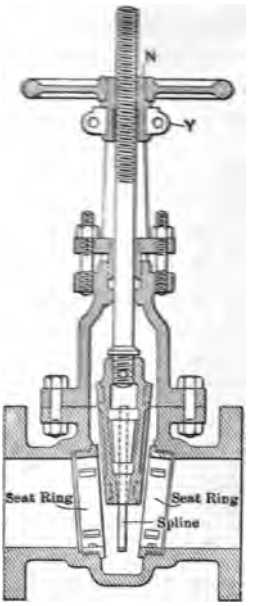



Fig. 107. Outside Screw.

Gate Valves.

*Gate Valves.*—This type of valve gives very little resistance to the flow of steam or liquid passing through it, and is generally used in the best class of work. The general construction of the Chapman valve is shown in Figs. 106 and 107, which represent

the "inside screw" and "outside screw" or yoke patterns, respectively. In the former the spindle remains stationary so far as any vertical movement is concerned, and the gate or plug being attached to it by means of a threaded nut, rises into the bonnet when the spindle is revolved. With this form of valve it is impossible to tell by its appearance whether it is open or closed unless provided with some special device for indicating the open and closed positions. With the outside screw, the upper portion of the spindle is threaded and the spindle is operated by a revolving nut *N*, held vertically in the yoke *Y*, and turned by the hand wheel which is fastened to it. The operating screw of these valves is entirely outside the valve body where it can be inspected and oiled, thus insuring easy operation. The spindle rises through the stuffing box without turning, which allows the packing to be kept tight without difficulty. When valves of this type are used, the attendant can tell at a glance whether they are open or closed.

The gate or plug is made wedge shaped and presses against ground seats when closed. The seats are made both solid and removable, and of various materials for different pressures. Gate valves of different makes vary chiefly in the small details of construction.

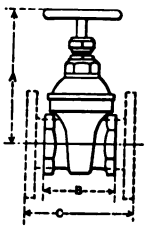
In the Ludlow valve the plug or gate is made up of two parts having the outer faces parallel instead of being wedge-shaped as in the case of the Chapman valve. The backs of these two parts are wedge shaped, so that when the valve is closed, the plug first descends and loosely closes the opening; then a further movement of the stem forces the wedges slightly past each other and presses the outer surfaces tightly against the seats.

In certain forms of the Fairbanks valve the distinctive feature is a metal cage which holds the seat rings in place. With valves of this form, the rings can be renewed by simply taking off the bonnet and without removing the valve from the pipe line. A special seat ring of vulcanized absestos is used in this type of valve.

Tables LIV., LV. and LVI. give the over-all dimensions of standard weight Chapman valves of different patterns.

*Choosing a Valve.*—Care should always be taken to select a valve in which the material of the seat or ring is suited to the pressure to be carried. Bronze seats are commonly used for

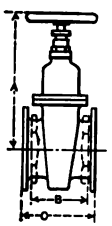
## TABLE LIV.



BRONZE, SCREW-TOP GATE VALVES.

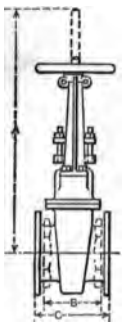
| Diameter of port, inches | ¾ | 1 | 1¼ | 1½ | 2 | 2½ | 3 | 3½ |
|---|---|---|---|---|---|---|---|---|
| A | 5¼ | 5 1/16 | 6 5/16 | 6 1/16 | 7⅝ | 9 5/16 | 10⅜ | 12 7/16 |
| B | 2⅜ | 2⅝ | 3¼ | 3½ | 4 | 4⅜ | 5⅜ | 6¼ |
| C | | | 3 1/16 | 4 5/16 | 5¼ | 5⅜ | 7 | 8¼ |

## TABLE LV.



IRON BODY, BOLT TOP, INSIDE SCREW, GATE VALVES.

| Diameter of port, inches | 3 | 4 | 5 | 6 | 7 | 8 | 10 | 12 |
|---|---|---|---|---|---|---|---|---|
| A | 12½ | 14 5/16 | 18⅛ | 21 5/16 | 23½ | 25⅞ | 30 5/16 | 34 1/16 |
| B | 7½ | 9⅛ | 10½ | 11⅜ | 12⅛ | 12⅝ | 13⅞ | 14⅞ |
| C | 8¼ | 9⅜ | 9⅜ | 10⅝ | 11⅛ | 11⅝ | 13⅜ | 14⅝ |



## TABLE LVI.

IRON BODY, BOLT TOP, OUTSIDE SCREW, GATE VALVES.

| Diameter of port, inches | 5 | 6 | 8 | 10 | 12 | 14 | 16 | 20 |
|---|---|---|---|---|---|---|---|---|
| A | 29½ | 34⅜ | 42 | 51½ | 58⅛ | 66 | 75⅜ | 90½ |
| B | 10½ | 11⅜ | 12½ | 13⅞ | 14½ | | | |
| C | 9⅜ | 10⅞ | 11⅞ | 13⅜ | 14⅝ | 15⅞ | 18⅜ | 21 |

pressures over 80 pounds, unless the babbit metal or other material employed is especially prepared for higher pressures and guaranteed by the makers.

For reasons already stated, outside screw valves are preferable for high-pressure work, and especially so for the larger sizes. In the case of low-pressure heating work, the inside screw is more commonly used.

*Locating Gate Valves.*—A gate valve should never be placed in a steam pipe with the spindle downward, for if only partially opened, the gate projecting from the bottom upward, will form a pocket for holding back the condensation, and may thus be

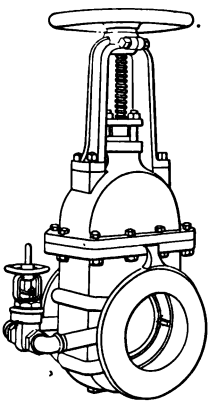


Fig. 108. By-pass Valve.

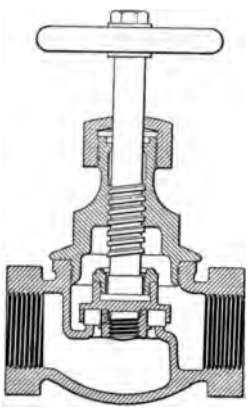


Fig. 109. Globe Valve.

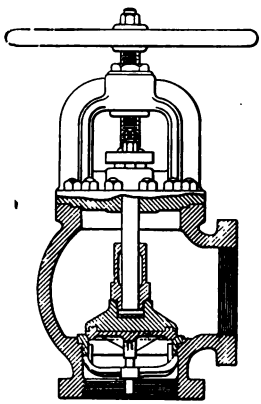


Fig. 111. Angle Valve.

the cause of serious injury to the plant. When placed with the stem extending upward or in a horizontal position a clear passage is provided at the bottom of the pipe. Valves are made in different weights and the pressure to be carried should always be stated when they are specified.

*By-pass Valves* should be used in high-pressure work for sizes 8 inches in diameter and over. A by-pass valve is shown in Fig. 108. There are two advantages in the use of by-pass valves in high-pressure lines. First, when the valve is closed, there is an enormous pressure acting on one side of the gate which makes it very hard to start, and also as it is pressed so tightly against the seat on the side opposite the pressure, it is apt to score the smooth surfaces of the gate and seat when opened. When used in the supply pipe to an engine it is desirable to admit steam very

slowly when "warming up," and this is much more easily accomplished by means of a small by-pass valve which is easily operated, than by the use of the main valve itself.

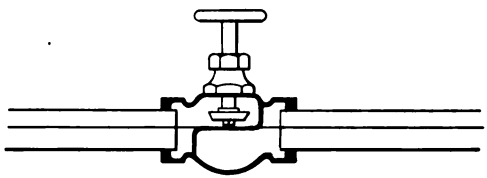


Fig. 110.

*Globe Valves.*—A form of globe valve is shown in Fig. 109. This is known as a disc valve, and has a renewable seat; other patterns have solid seats of different forms. A globe valve should

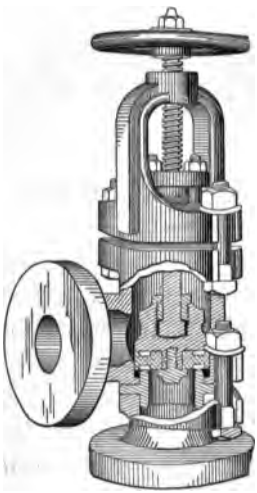


Fig. 112. Cadman Blow-off Valve.

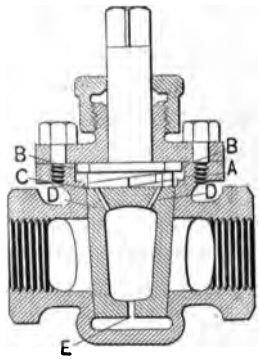



Fig. 113. Homestead Blow-off Cock.

always be set to close against the pressure, for if placed in the opposite way it could not be opened if the valve should become detached from the stem, and no indication of the trouble would be given by the action of the stem under these conditions.

Globe valves should never be placed in a horizontal steam or dry return pipe with the stem in a vertical position. The reason for this is made evident in Fig. 110 which shows by the middle line the height to which the condensation must rise before it can flow through the port or opening.

*Angle Valve.*—These valves are sometimes used to take the place of elbow fittings. They are a form of globe valve with the inlet at the bottom and the outlet at the side. The larger sizes have a guide spindle extending below the valve seat as shown in Fig. 111, while in the smaller sizes this is omitted.

Table LVII. gives the principal dimensions of Crane high-pressure angle valves. (See Fig. 111.)

TABLE LVII.

DIMENSIONS OF CRANE, HIGH-PRESSURE ANGLE VALVES.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Diameter of port..... | 2½ | 3 | 4 | 5 | 6 | 8 | 10 | 12 |
| Center to face, screwed ends.. | 5½ | 5⅝ | 6½ | 7⅝ | 8½ | 10 | 11⅝ | .. |
| Center to face, flange ends..... | 5⅞ | 6¼ | 7 | 7⅝ | 8⅝ | 10½ | 12½ | 14 |
| Center of port to top of wheel. | 13½ | 14⅞ | 17½ | 19¼ | 21¼ | 24 | 26⅝ | 36 |

As in the case of fittings, the dimensions of valves vary somewhat with different makers, but the general dimensions given above will be found useful in approximating the space required in any particular case.

*Radiator Valves.*—The various forms of radiator valves, of which there are several patterns, will be taken up under steam and hot-water heating.

*Blow-off Valves and Cocks.*—The blow-off pipe of a boiler is usually provided with a plug cock, having a gate valve placed between it and the boiler as a safeguard in case of leakage. Special blow-off valves are sometimes used in place of the cock and valve. These are made very heavy and are so designed that it is difficult for dirt or scale to lodge beneath the seat. Fig. 112 shows the Cadman blow-off valve which is constructed upon these principles.

The difficulty experienced with the ordinary plug or blow-off cock is its liability to leak unless set down very tightly against

its seat, in which case it is apt to stick, especially when first starting it. To overcome this difficulty, special forms have been designed, among which the Homestead locking cock shown in Fig. 113 is a good illustration. This is provided with a cam *A*, so arranged that after the cock is closed a further movement of the stem in the same direction forces the plug firmly against its seat. A slight movement in the opposite direction releases the cam and allows the plug to turn easily to the open position. The balancing ports *E*, *D*, *D* allow the pressure to enter the spaces above and below the plug, and as the upper end is the larger the pressure upon it is slightly greater, and therefore holds the plug lightly against its seat while open.

*Check Valves.*—When it is necessary that the flow of steam or water shall always take place in the same direction, check valves are employed. There are several forms of these in use, the most common of which is the swing check shown in Fig. 114. The seat in this valve is placed at an angle of about 45 degrees

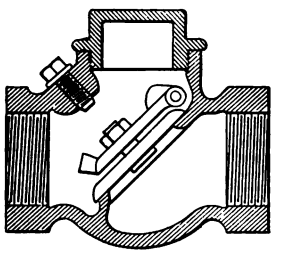


Fig. 114. Check Valve.

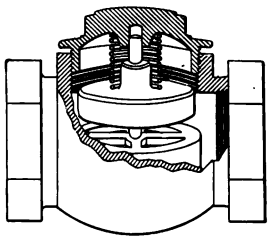


Fig. 115. Spring Check.

to the direction of flow. The valve or "clapper" is fitted somewhat loosely where it is fastened to the swinging arm, so that it may properly seat itself. This form is usually preferred in heating work as it gives less resistance to the flow of steam or water, and by its construction offers but little opportunity for scale or sediment to lodge upon the seat. When it is desired to reduce the resistance to a minimum, the check may be turned partially on its side or a special aluminum valve may be used.

The Locke spring check shown in Fig. 115 is especially adapted for use in boiler feed pipes where the feed-water is supplied by a

pump. The valve being held in place by a light spring is prevented from beating against the seat between the strokes of the pump. Check valves are placed in boiler-feed and return pipes, in the discharge pipes from traps, and various other places where it is desired to prevent the pressure in one pipe from "backing" into another, as when several return pipes from a building are brought into a common receiving tank. When used in a return pipe the check should always be placed below the water line if possible.

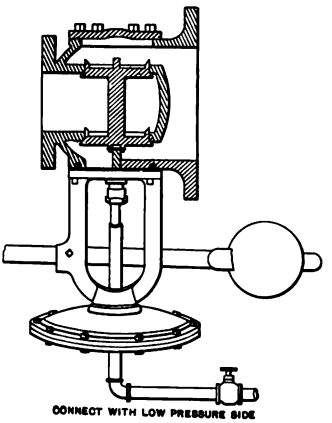



Fig. 116. Kieley Reducing Valve.

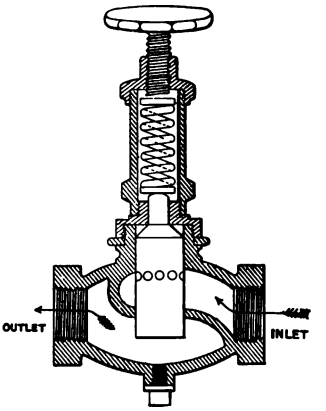



Fig. 117. Watson Reducing Valve.

*Pressure Reducing Valves.*—It is often necessary to provide steam at different pressures in the same building, as in the case of a combined power and heating plant. In this case the reduction in pressure is accomplished by passing the steam through a reducing valve. There are many different forms of these valves, all acting more or less upon the same general principles. In the Kieley valve, shown in Fig. 116, the low pressure steam acts on the lower side of a flexible diaphragm, and the weighted lever, which may be adjusted to give the desired reduction in pressure, acts upon the other side. The movement of this diaphragm causes a balanced valve to open or close as may be necessary to maintain the desired lower pressure.

Another form, in which the weighted lever is replaced by a spring and the diaphragm by a piston valve, is well illustrated by the Watson reducing valve shown in Fig. 117. In this case the reduced pressure acts upon the lower end of a piston valve which is balanced between this pressure and an adjustable spring at the top. As the piston simply passes through the inlet chamber its action is not affected by the high-pressure steam surrounding it. There are several good valves in use which embody the same principles or a combination of the two. Those shown are among the simplest and are therefore well adapted for purposes of illustration.

When the reduction in pressure is large, as in the case of a combined power and heating plant, the valve may be one or two sizes smaller than the low-pressure main into which it discharges. For example—a 5-inch valve will supply an 8-inch main, a 4-inch a 6-inch main, a 3-inch a 5-inch main, a 2½-inch a 4 inch main, etc.

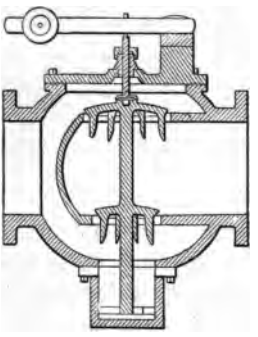


Fig. 118. Kieley Back-Pressure Valve.

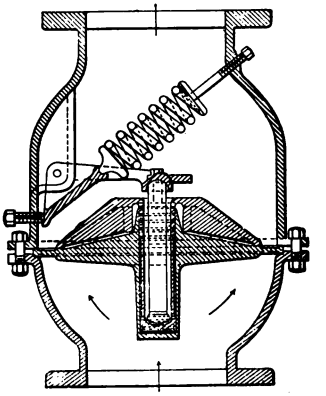


Fig. 119. Foster Back-Pressure Valve.

For the smaller sizes the difference should not be more than one size. All reducing valves should be provided with a valved by-pass and cut-out valves for use in case of repairs.

*Back Pressure Valve.*—This is a form of relief valve which is placed in the outboard exhaust pipe from an engine to prevent

the pressure in the heating system from rising above a given point. Its office is the reverse of the reducing valve which supplies more steam when the pressure becomes too low. The Kieley valve shown in Fig. 118 is designed for a horizontal pipe. The valve proper consists of two discs of unequal size, the combined area of which equals that of the pipe. The force tending to open the valve is that due to the steam pressure acting upon a surface equal to the difference in area between the two discs; it is clear from the cut that the pressure acting on the larger disc tends to open the valve while the pressure on the smaller acts in the opposite direction. The valve stem is connected with a weighted lever as shown. As the valve opens the weight is raised so that by placing it in different positions on the lever arm the valve will open at any desired pressure.

Fig. 119, (the Foster valve), shows a different type in which a spring is used instead of a weight. This valve has a single disc moving in a vertical direction. The valve stem is in the form of a piston or dash-pot which prevents a too sudden movement and makes it more quiet in its action. The disc is held on its seat against the steam pressure by a lever attached to the spring as shown. When the pressure of the steam on the underside becomes greater than the tension of the spring, the valve lifts and allows the steam to escape. The tension of the spring can be varied by means of the adjusting screw at its upper end.

A back-pressure valve is simply a low-pressure safety valve designed with a specially large opening for the passage of steam through it. They are made for both vertical and horizontal pipes.

## CHAPTER XIV.

### SPECIAL APPARATUS.

*Feed Pumps.*—Boilers are usually fed by small direct acting steam pumps, although power pumps driven by the engine are sometimes used. The former require a large amount of steam in proportion to the power delivered, but this is small in comparison with that generated by the boilers, and is offset by certain advantages which this type of pump has over the power pump.

The speed of the steam pump may be easily regulated to furnish the required amount of feed water under varying conditions, while with the power pump it is necessary to run it at a constant speed and allow the excess of water to flow back into the suction

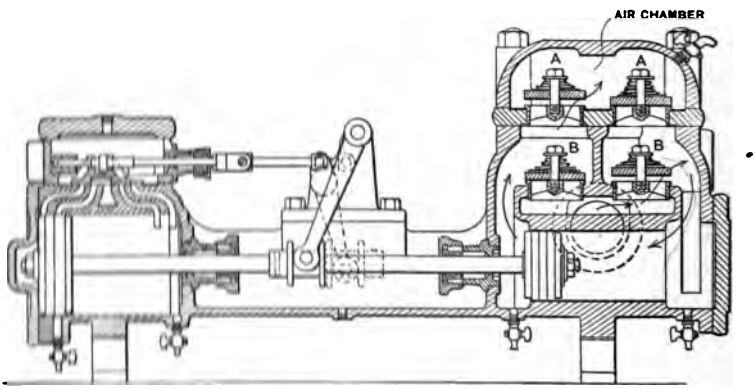



Fig. 120. Direct-Acting Piston Pump..

pipe through a relief valve. A section through a double acting piston pump is shown in Fig. 120. In construction it is like an ordinary slide valve steam engine with a water piston in place of the usual crosshead. The movement of the piston forces a part of the water in front of it through the upper valves *A A* into the air chamber, from which it flows through the discharge pipe to the boiler. On account of the partial vacuum formed back of the piston by its forward movement, water will be drawn by suction

into the cylinder through the valves *B B*, as indicated, ready for delivery on the return stroke. The valves are kept on their seats by light springs until the excess of pressure on the lower side is sufficient to lift them and allow the water to flow through.

*Plunger Pumps.*—The principal objection to the above type of pump is the difficulty experienced in keeping the piston tight and of detecting leaks when they occur. On this account the plunger pump is often preferred. Fig. 121 shows the water end of a

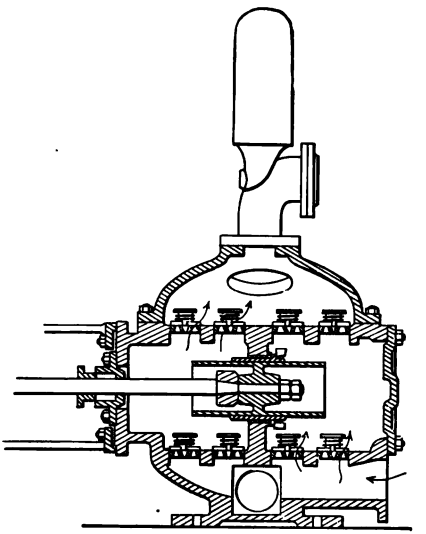


**Fig. 121. Water End of Plunger Pump.**

double-acting single plunger pump. The advantage of this form over the piston is the ease with which it is kept tight under high pressures, and with gritty liquids the wear is taken by the bushing, which is more easily and cheaply replaced than a cylinder lining. In order to examine or repack either of these forms it is necessary to dismantle the pump.

The plunger pump shown in Fig. 122 can be repacked from the outside. This is indicated more plainly in Fig. 123, and any leakage may at once be detected. When two cylinders are placed side by side and discharge into a common delivery pipe, it is called a *duplex* pump.

*Capacity of Pumps.*—Theoretically, the quantity of water delivered by a pump in a given time is equal to

Area of plunger × length of stroke × number of strokes.

Practically, there is a certain amount of leakage around the

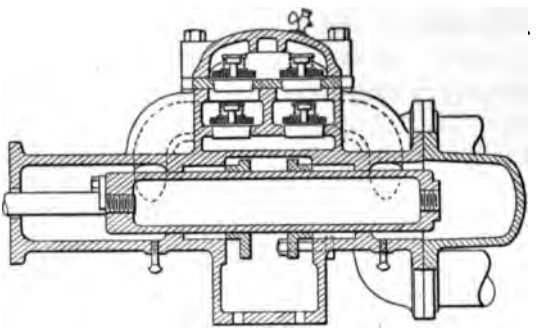


Fig. 122. Outside-Packed Plunger Pump.

plunger and through the valves called "slip." This brings the actual capacity down to about 80 per cent of the theoretical in well-made pumps of medium size working under ordinary conditions.

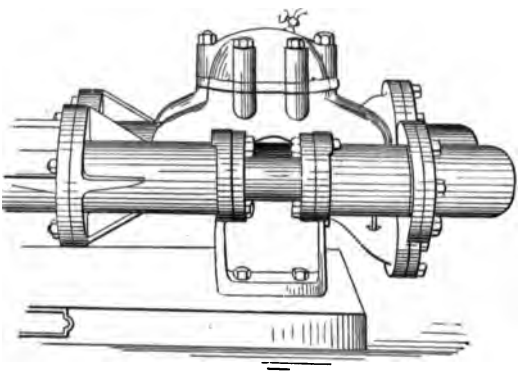


Fig. 123. Exterior View Showing outside Glands.

Table LVIII. gives the capacities of standard duplex feed pumps for various speeds. These figures are based on 30 pounds of water per hour per boiler horse power, and 80 per cent slip. The speed of a pump is often expressed in piston speed instead of

strokes per minute. This should not exceed 100 feet per minute as a maximum, and 50 feet or less for continuous working is better.

The size of a pump is indicated by three dimensions, as 2 in. x 1⅛ in. x 2¾ in., in which the first is the diameter of the steam cylinder, the second the water cylinder, and the third the length of stroke. The proportions given in the table are for moderate to high steam pressures. If it is desired to operate the

## TABLE LVIII.

### CAPACITIES OF BOILER FEED PUMPS.

| Size of pump | 30 strokes per minute | | 45 strokes per minute | | 60 strokes per minute | | Approximate floor space | Steam pipe | Exhaust pipe | Suction pipe | Discharge pipe |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lb. per hour | Horse power | Lb. per hour | Horse power | Lb. per hour | Horse power | | | | | |
| In. In. In. | | | | | | | In. In. | In. | In. | In. | In. |
| 2 by 1⅛ by 2¾ | 198 | 7 | 297 | 10 | 396 | 13 | 5 by 20 | | ½ | 1 | ¾ |
| 3 " 1¾ " 3 | 720 | 24 | 1080 | 36 | 1440 | 48 | 9 " 25 | | ½ | 1¼ | 1 |
| 4½ " 2¾ " 4 | 2316 | 77 | 3474 | 116 | 4632 | 154 | 12 " 33 | | ¾ | 2 | 1½ |
| 5¼ " 3½ " 5 | 4800 | 160 | 7200 | 240 | 9600 | 320 | 14 " 38 | | 1¼ | 2½ | 1½ |
| 6 " 4 " 6 | 7530 | 250 | 11295 | 376 | 15060 | 502 | 15 " 44 | | 1½ | 3 | 2 |
| 7½ " 4½ " 6 | 9600 | 320 | 14400 | 480 | 19200 | 640 | 19 " 48 | 1½ | 2 | 4 | 3 |

pump at a pressure much less than 20 pounds, it should be provided with larger steam cylinders, depending upon the pressure at which it is desired to run it. In designing a boiler plant it is best to use two pumps of such capacity that one of them running at a speed of 50 or 60 strokes per minute will deliver the maximum quantity of water required under ordinary conditions. This makes easy work for the two running together and allows a reserve pump in case of a breakdown. The following data relating to water will be found useful in making calculations for the capacity of pumps:—

Cubic feet × 60 = pounds.
Pounds ÷ 60 = cubic feet.
Gallons × 8.3 = pounds.
Pounds ÷ 8.3 = gallons.
Cubic feet × 7.2 = gallons.
Gallons ÷ 7.2 = cubic feet.

These figures will vary slightly for different temperatures, but are sufficiently accurate for ordinary use.

*Automatic Return Pumps.*—In exhaust heating plants the condensation is commonly returned to the boilers by means of a return pump. A combined pump and receiver of the form illustrated in Fig. 124 is generally used. This consists of a cast or wrought-iron tank mounted on a base in connection with a boiler feed pump. Inside of the tank is a ball float connected by means

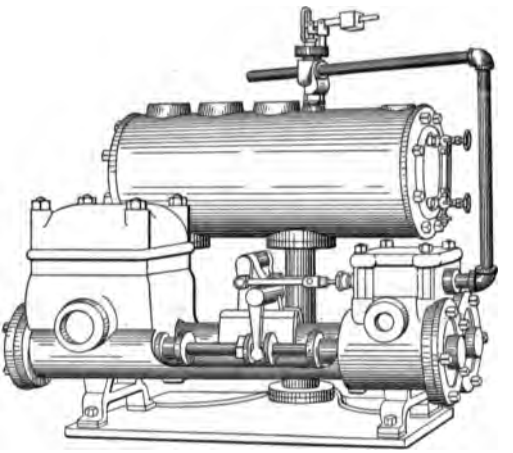


Fig. 124. Automatic Return Pump.

of levers with a valve in the steam pipe; when the water line in the tank rises above a certain level, the float is raised and opens the steam valve which starts the pump. When the water is lowered to its normal level the valve closes and the pump stops. By this arrangement a constant water line is maintained in the receiver and the pump runs only as needed to care for the condensation as it returns from the heating system. If dry returns are used they may be brought together and connected with the top of the receiver. If it is desired to seal the horizontal runs, as is usually the case, the receiver may be raised to a height sufficient to give the required elevation and the returns connected near the bottom below the water line.

A "balance pipe," so called, should connect the heating main with the top of the tank for equalizing the pressure, otherwise the steam above the water would condense and the vacuum thus

TABLE LIX.

CAPACITIES OF COMBINED PUMPS AND RECEIVERS.

| Size of pump, inches | | | Over all dimensions, inches | | |
|---|---|---|---|---|---|
| Steam cylinders | Water cylinders | Length of stroke | Length | Width | Height |
| 3 | 2 | 3 | 37 | 22 | 34 |
| 4½ | 2¾ | 4 | 38 | 28 | 34 |
| 5¼ | 3½ | 5 | 41 | 30 | 41 |
| 6 | 4 | 6 | 44 | 31 | 42 |
| 7½ | 4½ | 6 | 56 | 36 | 41 |

formed would draw all the water into the tank leaving the returns practically empty and thus destroying the condition sought.

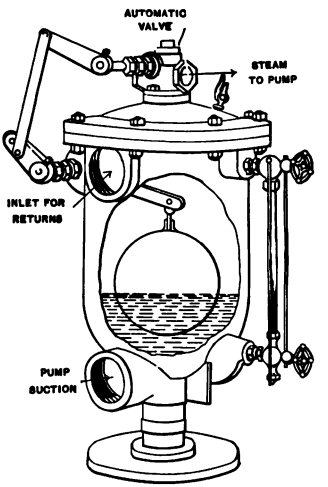



Fig. 125. Mueller Pump Governor.

Table LIX. gives the over-all dimensions of the Deane combined pump and receiver as shown in Fig. 124.

Although the returns from a heating system are often connected directly into the top of the receiver, it is better practice to join them below the water line. With this arrangement each return is sealed, and any slight difference in pressure is balanced by the water column in the vertical portion of the pipe.

*Pump Governors.*—These are often used in connection with a return pump in place of a receiving tank. They operate upon the same principle, the only difference being that the receiving chamber is made only large enough to accommodate the float which actuates the automatic valve, instead of serving also as an overflow for the condensation from the returns.

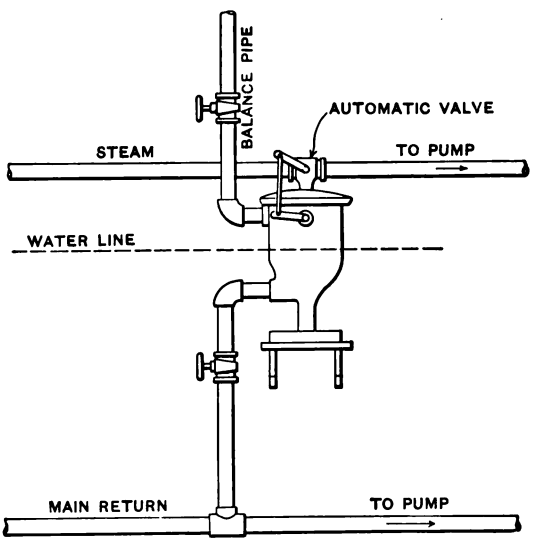



Fig. 126. Connections for Pump Governor.

Fig. 125 shows the Mueller pump governor or regulator, the operation of which is evident from the cut. In case it is desired to raise the water line in order to seal the returns, the regulator may be raised to the required height upon a support, and the connections made as shown in Fig. 126. The upper opening in this arrangement is used for the connection of a balance or equalizing pipe instead of the inlet as before.

**Traps.**

Traps are used for draining the water of condensation from steam pipes, coils, heaters, etc., without allowing the steam to escape at the same time. There are a great many different forms, most of them, however, coming under the heads of *float, bucket,* and *expansion* traps. Fig. 127 shows the Curtis trap, a simple form of the first type. When the water line reaches a certain point, the float rises and opens the discharge valve *A,* which is placed near the bottom of the trap. As the water flows out, the float falls, and the valve closes before being uncovered, so that no steam is allowed to escape.

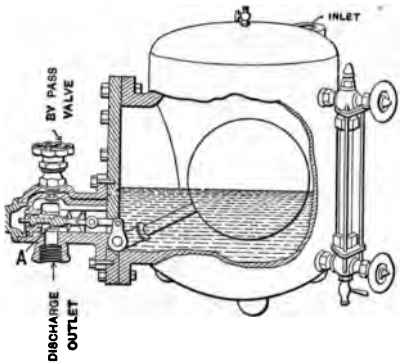



Fig. 127. Float Trap.

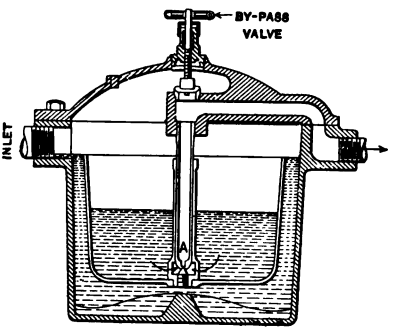



Fig. 128. Bucket Trap.

*Bucket Traps.*—A bucket trap is shown in Fig. 128. In this case the entering water fills the space around the bucket and floats it, thus closing the valve *A.* After the space becomes filled, the water overflows into the bucket, causing it to sink. As the conical plug is attached to the bucket, the valve is opened, and the water flows through openings in the surrounding sleeve, as indicated by the arrows, and is forced upward through the inner tube by the steam pressure acting upon its surface. As soon as the bucket is partly emptied it again rises and closes the valve before the opening has become uncovered to admit the passage of steam. Both of the traps above described are provided with by-pass valves for blowing out.

*Expansion Traps.*—Fig. 129 shows the interior mechanism of the Heintz expansion trap. The valve closing the discharge opening in this case is attached to the end of a curved tube partially filled with a volatile fluid. Water entering the trap at a temperature below 212 degrees will flow through without closing the valve, but as soon as its temperature reaches this point, which is that of steam at atmospheric pressure, the vapor within the tube exerts a sufficient pressure to partially straighten it and thus

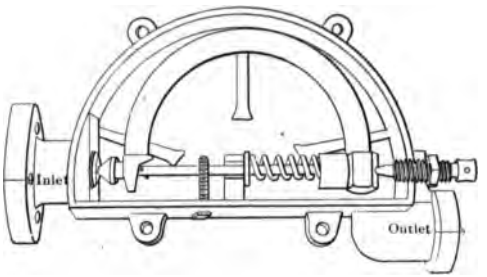



Fig. 129. Heintz Expansion Trap..

completely closes the valve. The valve is in a wide open position when the temperature of the water is from 194 to 197 degrees, but is not completely closed until it reaches 212 degrees.

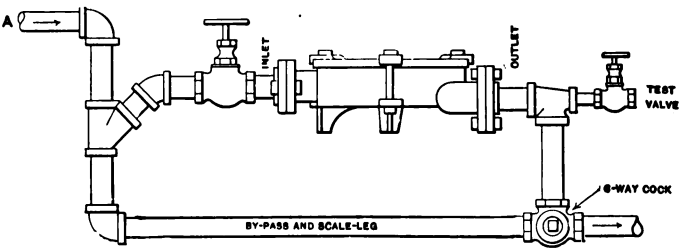



Fig. 130. Connections for Heintz Trap.

Fig. 130 shows the method of connecting up this type of trap. The pipe *A* should always be of sufficient length to allow the condensation to cool to a point below 212 degrees before reaching the trap. When two or more traps discharge into the same line, a check valve should always be placed in the outlet pipe.

Other expansion traps are operated by the expansion and contraction of tubes and rods made of iron and brass; the difference in the expansion of these two metals under the same conditions of temperature being made to open and close a valve in a similar manner to the trap just described.

*Location of Traps.*—Traps are usually placed below the pipe or a system of pipes to be drained, although they will operate in many cases if placed at a higher level. This is true because as soon as the pocket in the pipe leading to the trap is filled with water, it cuts off the supply of steam to the body of the trap, thus causing a vacuum which allows the water to be forced upward by the pressure in the system back of it. In case a trap discharges against atmospheric pressure, it will raise the water to a height of about 2 feet for each pound steam pressure within the trap.

All traps should be provided with a valved by-pass and cut-out valves; and where several discharge into a common main, it is well to place a check valve in the discharge pipe from each. Traps for low and high-pressure work are slightly different, and the pressure they are to operate under should always be mentioned when purchasing or specifying.

*Return Traps.*—The traps just described can only discharge their contents against a lower pressure.

A return trap is a device commonly used for receiving the condensation under a low pressure and discharging it back into the boiler against a much higher pressure. They are simple in construction and are often used instead of a pump in plants of small size. The Bundy return trap shown in Figs. 131 and 132 is a good illustration of this form of trap. It consists of a cast-iron bowl pivoted at $M$ and $N$. There is an opening through $N$ connecting with the inside of the bowl. The pipe $D$ (Fig. 132), leading from the steam space of the boiler, connects through the valve $C$ with an interior pipe opening near the top as shown in Fig. 131.

As the bowl fills with water from the receiver, it overbalances the weighted lever and falls to the bottom of the ring. This opens the valve $C$ and admits steam at boiler pressure to the top of the bowl. Since the pressures above and below the water in

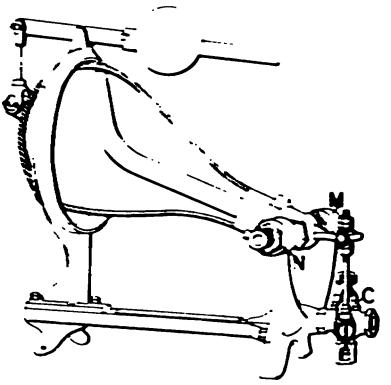



**Fig. 131. Bundy Return Trap.**

the trap are equal, it flows into the boiler of its own weight through the pipe *H*. After the water is discharged from the trap the weighted lever raises the bowl and closes the valve *C*.

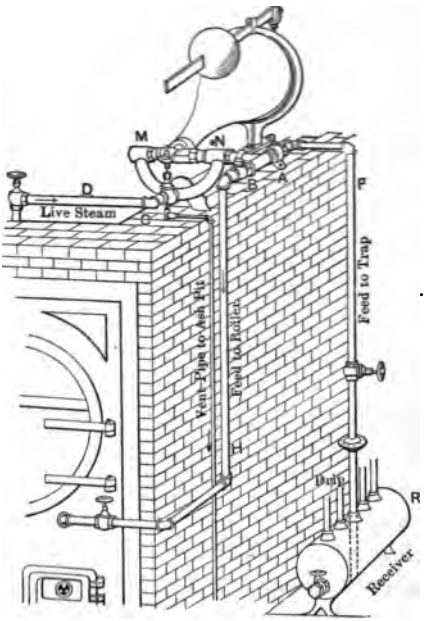



**Fig. 132. Connections for Bundy Trap.**

While boiler pressure is on the trap the check valve *A* prevents it from entering the feed pipe *F*. After the valve *C* closes, the steam remaining in the bowl soon condenses, thus forming a vacuum which draws up another supply of water from the receiver *R*, and the operation is repeated. While the bowl is filling, water from the boiler is kept from entering through pipe *H* by means of the check valve *B*.

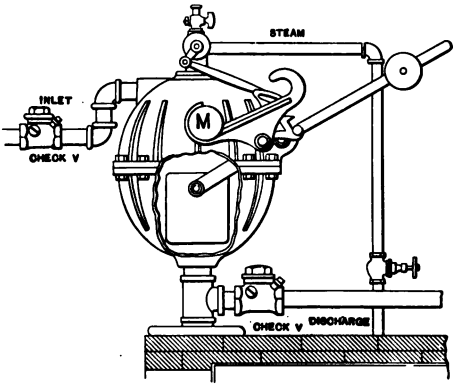



**Fig. 133. Pratt Return Trap.**

In order to work satisfactorily, the trap should be placed at least 3 feet above the water level in the boiler. Sometimes the trap is provided with a small vent which opens when the valve *C* closes and admits atmospheric pressure to the bowl. In this case the pressure in the returns must always be sufficient to raise the water from the receiver to the trap, which theoretically, is about 1 pound for every 2 feet in height. In practice there will be more or less friction to overcome, and suitable adjustments must be made for each particular case.

In the Pratt return trap shown in Fig. 133 the equalizing valve is opened and closed by the action of a float and connecting levers.

There are several makes of return traps of different design, but all working upon practically the same principle, that is, the equalization of pressure in the trap and boiler.

**Separators and Grease Extractors.**

*Steam Separators.*—If the water surface of a boiler is not sufficiently large for the free disengagement of the steam, a certain amount of moisture will be carried over in the form of spray; also, if steam is carried for some distance in a pipe, condensation will take place to a greater or less extent, depending upon the length of the pipe and its protection from the surrounding air. For the best results, steam should be delivered to an engine as dry as possible, and to provide for this, separators are commonly used. One form consists of a drum of considerable size, in which the current of steam comes to rest; the entrained water falls to the bottom and is drained away, while the .dry steam flows from the top. In order to be effective the drum must be of ample size, or the water and steam will not be separated. There are several forms designed upon the principle that if the direction of a current of steam is suddenly changed, or if it flows downward and then upward, the water will be separated from the steam and fall to the bottom of the chamber in which the separation takes place. In the Stratton separator shown in Fig. 134 the steam enters at one side of a cylinder, flows downward with a rotary motion and then upward through a pipe at the center. Dry steam escapes from an opening near the top on the opposite side from which it enters, and the separated water is trapped away from the bottom. The Cochrane separator in Fig. 135 is of the baffle plate type. The connections for the entrance

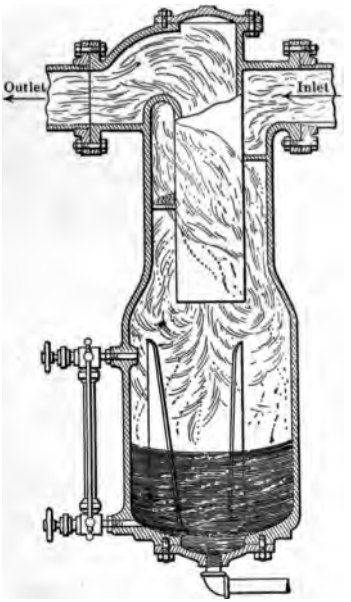



Fig. 134. Stratton Separator.

and exit of the steam project from each side of a spherical head. The baffle plate, which is cast as a part of the head, is ribbed or corrugated, and has ports at each side for the passage of the steam. The area of these ports is made large to prevent loss of pressure by friction. Steam entering at the left-hand opening strikes the baffle plate and passes to the outlet chamber by means of the side ports shown in the cut. Separators are made in a great variety of forms, many of which are modifications of the general types above shown. In others the steam is given a whirling motion, and centrifugal force is relied upon to separate the water from the steam. They are made for use in both vertical and horizontal pipes.

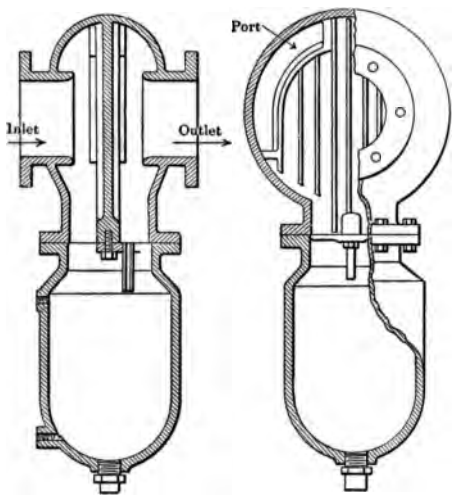



**Fig. 135. Cochrane Separator.**

*Grease Extractors.*—When the exhaust steam from engines and pumps is used for heating, provision must be made for removing the oil before the steam enters the heating system. This must be done for two reasons: First, a coating of oil or grease upon the inside of the radiators tends to reduce their efficiency as heating surface; and second, the presence of oil in the water of condensation returned to the boiler will give trouble in various ways. The latter is of the most importance and may cause foaming of the

water, pitting of the plates, or increase the tendency to incrustation. There are various devices for removing the oil from steam. Some of these consist of a series of baffle plates against which the

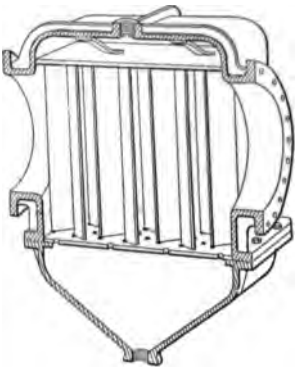


Fig. 136. Webster Oil Separator.

particles of oil lodge as the steam passes among them. Fig. 136 shows the Webster oil separator which is of this form. Others

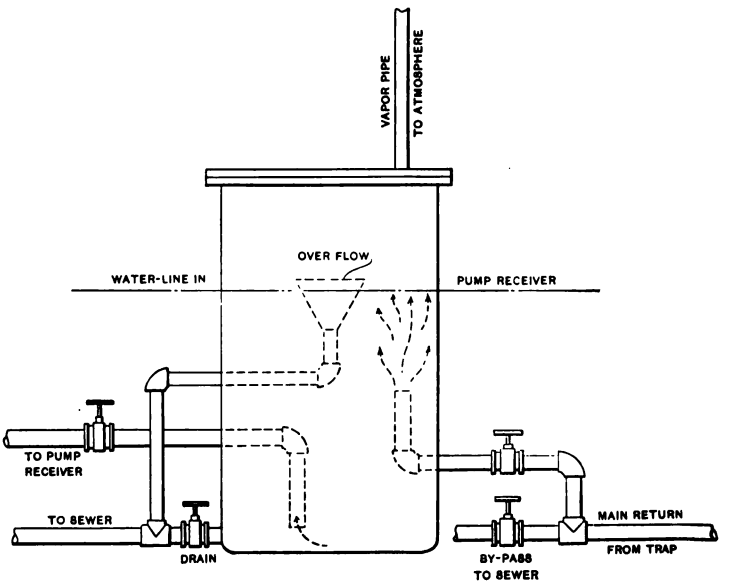



Fig. 137. Oil Separator and Purifier.

depend upon the centrifugal action of the heavier particles of oil and water, and the steam is given a rotary motion which throws the oil to the outer walls of a collecting chamber, from which it trickles down to a receiver and is trapped away to the sewer. In other forms the steam is made to pass through a layer of excelsior, coke, or small pebbles.

Sometimes, as an extra precaution, the water of condensation is again purified before it is returned to the boilers. A simple arrangement for this purpose is shown in Fig. 137. The settling chamber may be made of cast or wrought iron, about 24 inches in diameter by 48 inches in height. The condensation from the heating system is trapped into the tank near the bottom, the discharge pipe ending in an elbow looking up. A second pipe connects the bottom of the tank with the automatic pump receiver, thus causing the water to stand at the same level in both. An overflow pipe ending in a tunnel inside the tank is provided as shown, the top of the tunnel being placed about an inch above the normal water line in the pump receiver. As the condensation is trapped into the tank the oil which it contains will rise to the surface, while the clearer water flows from the bottom of the tank into the pump receiver and is automatically returned to the boiler. By closing the discharge valve *A* occasionally, the water line is made to rise above the top of the tunnel and the oil overflows into the drain or sewer.

### Feed Water Heating.

*Feed-Water Heaters.*—Feed-water heaters are employed for two important reasons: First, if cold water is introduced into a boiler in any considerable quantity, the cooling effect will cause an unequal contraction of the plates, which is likely to produce leaks at the joints. It also tends to reduce the steam pressure, and necessitates more rapid firing for a time after feeding, unless the load upon the engines is practically constant, so that the feed valve can be set to supply a uniform quantity of water continuously.

Second, feed-water heaters can nearly always be arranged to utilize exhaust steam, or waste gases from the furnace, so that a substantial saving in fuel is gained by their use.

*Saving by Heating the Feed Water.*—The percentage of saving in fuel by heating the feed water with waste products is expressed by the equation,

$$\frac{100\ (T_2 - T_1)}{L + (T_3 - T_1)}$$

in which

$T_1$ = initial temperature of the feed water entering the heater.
$T_2$ = final temperature of the feed water leaving the heater.
$T_3$ = temperature of the steam at boiler pressure.
$L$ = latent heat of evaporation for steam at boiler pressure.

*Example.*—What will be the saving in fuel by using an exhaust steam feed water heater under the following conditions: Initial temperature of feed water 60°, final temperature 205°, and steam pressure on boilers 80 pounds gauge?

From Table I. we find the temperature of steam at this pressure to be 324°, and the latent heat of evaporation 886.

Substituting these values in the above equation, we have,

$$\frac{100\ (205 - 60)}{886 + (324 - 60)} = \frac{14{,}500}{1{,}150} = 12.6\%$$

This is true because the total heat required per pound of steam is that necessary to raise the temperature of the feed water from 60° to 324°, which is $324 - 60 = 264$ B. T. U., plus that required to evaporate it into steam at this temperature, which is 886 B. T. U., making a total of $264 + 886 = 1{,}150$ B. T. U. The saving made by heating the feed water from 60° to 205° is $205 - 60 = 145$ B. T. U. Therefore the gain in per cent is

$$\frac{145 \times 100}{1{,}150} = 12.6$$

With the most economical multiple expansion engines only about 18 per cent of the heat stored in the steam leaving the boilers is transformed into work, and in the majority of engines, probably not more than 10 per cent is utilized. If we assume 15 per cent as an average, this leaves 85 per cent of the heat in the total amount of steam generated (neglecting cylinder condensation) available for heating purposes, and of this amount only

a comparatively small proportion can be used for feed-water heating under ordinary conditions. In office buildings, factories, or other buildings having their own power plant, this remaining portion is usually employed for warming and ventilating purposes.

*Heat Available for Feed-Water Heating.*—The proportion of heat in the exhaust steam which can be used for feed-water heating may be easily determined as follows: The latent heat of evaporation for steam at atmospheric pressure is 966 B. T. U. That is, each pound of steam gives out 966 heat units when it is condensed. The quantity of heat required for raising the temperature of 1 pound of water from 50° to 210°, which may be taken as maximum requirements, is $210 - 50 = 160$ B. T. U. Therefore only $160 \div 966$, or approximately one sixth of the heat in each pound of exhaust steam can be utilized in warming the pound of feed water which is to replace it.

Heaters using exhaust or live steam are divided into two kinds, known as open and closed heaters. When the waste gases from the furnace are employed, the apparatus is commonly called an *economizer.*

*Open Heaters* usually consist of a chamber of cast iron or steel plate, into which the steam is admitted. Cold water is fed in at the top, and in most forms is made to fall in thin sheets by flowing over shallow trays placed one below the other. The intimate contact of the water with the steam heats it to a temperature very nearly that of the steam. When the water contains scale forming salts which are precipitated at temperatures below that to which the water is heated, the sediment is caught by the trays and can be removed from time to time as required. Heaters of this form are sometimes provided with filters which still further purify the water before it is pumped to the boilers.

As the condensed steam is mixed with the feed water, it becomes necessary to pass the exhaust through an efficient oil separator before it enters the heater.

Fig. 138 shows a section through the Cochrane feed-water heater and purifier, which is of the type just described. The cold water enters at the top and trickles downward over the intercepting trays to the receiver at the bottom.

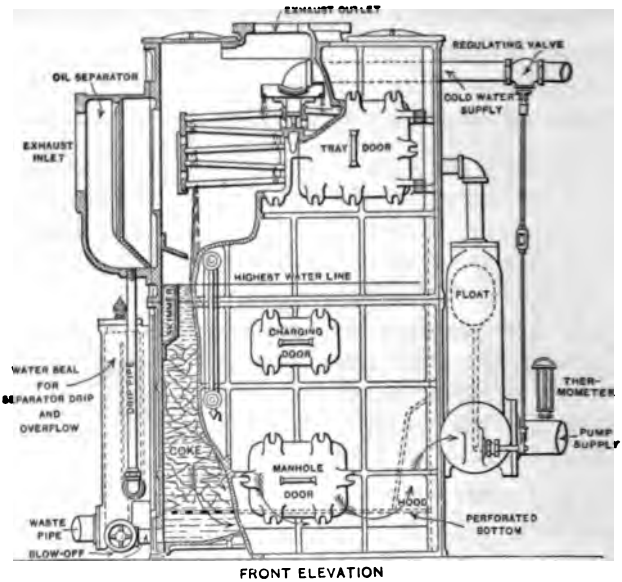



**Fig. 138. Cochrane Open Feed-Water Heater.**

When the water line in the receiver reaches a given point, a valve operated by a float closes the supply. Exhaust steam enters

TABLE LX.

DIMENSIONS OF COCHRANE FEED WATER HEATERS.

| Rated horse power | Diameter of exhaust connections | Height | Floor space |
|---|---|---|---|
| | In. | In. | In. In. |
| 50 | 4 | 67 | 21 by 27 |
| 100 | 6 | 75 | 25 " 31 |
| 200 | 8 | 75 | 30 " 36 |
| 450 | 10 | 87 | 38 " 46 |
| 600 | 12 | 93 | 42 " 51 |

at the side through an oil separator and passes out at the top of the heater. The oil from the separator is trapped to the sewer. When used in connection with a heating system the returns are

brought back and discharged into the receiver just below the water line. All drips from separators, steam jackets, etc., may be trapped into the receiver.

Before being pumped to the boilers the water passes through a coke filter at the bottom of the receiving chamber as indicated.

Table LX. gives the overall dimensions of a few of the principal sizes.

*Closed Heaters.*—With a closed heater the feed water does not mingle with the steam, but passes through a series of brass or copper tubes which are surrounded with steam on the outside. The Goubert heater shown in Fig. 139 is a good illustration of this type. In this heater, the cold feed is supplied at the bottom and the hot water taken from the top. Closed heaters are made for use in both vertical and horizontal positions, the former, however, on account of the small floor space required, is usually preferable, unless it is desired to suspend it overhead. There are various forms of construction employed, some having straight tubes, while in others the heating surface is in the form of a coil. When straight tubes are used one end is made to slide in a stuffing box attached to the tube sheet in order to provide for the unequal expansion of the iron shell and the brass or copper tubes.

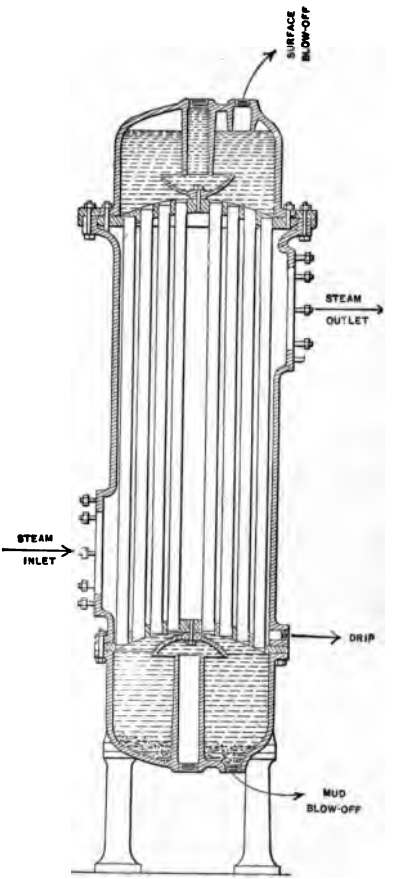



**Fig. 139. Goubert Closed Heater.**

The principal dimensions of some of the Goubert vertical heaters are given in Table LXI.

TABLE LXI.

DIMENSIONS OF GOUBERT VERTICAL HEATERS.

| Rated horse power | Diameter of exhaust connections | Diameter of water connections | Height | Diameter of shell |
|---|---|---|---|---|
| | In. | In. | Ft. In. | In. |
| 50 | 6 | 1¼ | 5 4 | 12 |
| 70 | 6 | 1½ | 6 6 | 12 |
| 100 | 6 | 1½ | 8 2 | 12 |
| 200 | 8 | 2 | 8 4 | 16 |
| 300 | 10 | 2½ | 8 9 | 21 |
| 400 | 10 | 2½ | 10 5 | 21 |
| 500 | 12 | 3 | 9 7 | 25 |
| 600 | 12 | 3 | 10 8 | 25 |
| 800 | 16 | 4 | 10 8 | 29 |
| 1000 | 16 | 4 | 12 4 | 29 |

*Heating Surface Required.*—The required amount of heating surface depends upon the initial temperature of the feed water, the steam pressure within the heater, and the velocity with which the water flows through the tubes.

With exhaust steam from non-condensing engines, it is customary to allow 1 square foot of heating surface for about each 90 pounds of water passed through the heater per hour. When the exhaust from condensing engines is used, the surface should be increased about 50 per cent, owing to the lower temperature of the steam. This calls for about ⅓ square foot of heating surface per horse power for non-condensing engines and ½ square foot for condensing.

The temperature to which the feed water may be raised usually varies from 200° to 210° with exhaust steam from non-condensing engines, and from 110° to 120° in the case of condensing engines.

*Heating Feed Water by Exhaust from Auxiliaries.*—In many condensing plants the exhaust from the various pumps and other auxiliaries is sufficient to heat the feed water for the entire plant. When the exhaust from these sources is equal to about one sixth of the entire quantity of steam generated by the boilers, there will be nothing gained by placing a heater in the main exhaust pipe leading to the condenser; but if the exhaust from the aux-

iliaries is less than this amount, the feed water may be first passed through a heater supplied with steam at condenser pressure, and then through a second heater taking the pump exhaust at atmospheric pressure, which will heat the water up to a temperature of about 205°.

**Economizers.**

*Construction.*—Economizers are commonly made up of rows of vertical cast-iron pipes about 4 inches in diameter and 9 feet high,

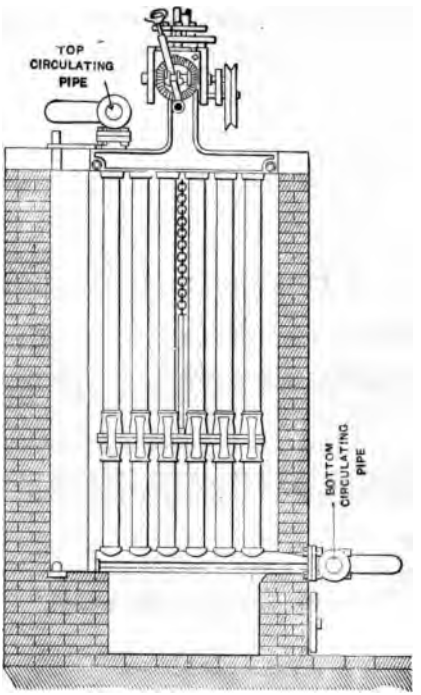



**Fig. 140. Section of Green Economizer.**

connected at top and bottom by headers, each header, in turn, being connected with pipes running lengthwise, one at the top and one at the bottom, outside the brick chamber enclosing the apparatus. Each tube is provided with a geared scraper which travels up and down continuously for the purpose of removing the soot as it collects.

A single section of the Green economizer with its surrounding brickwork is shown in Fig. 140. The mechanism for operating the scrapers is seen at the top and may be driven by a belt from some convenient shaft or by an independent engine or motor. The feed water is forced into the economizer by the boiler pump at the lower branch, nearest the point of exit of the gases, and leaves through the upper branch pipe at the other end.

The series of pipes and headers are enclosed in a brick chamber through which the furnace gases are made to pass on their way to the chimney. The space below the lower headers is for

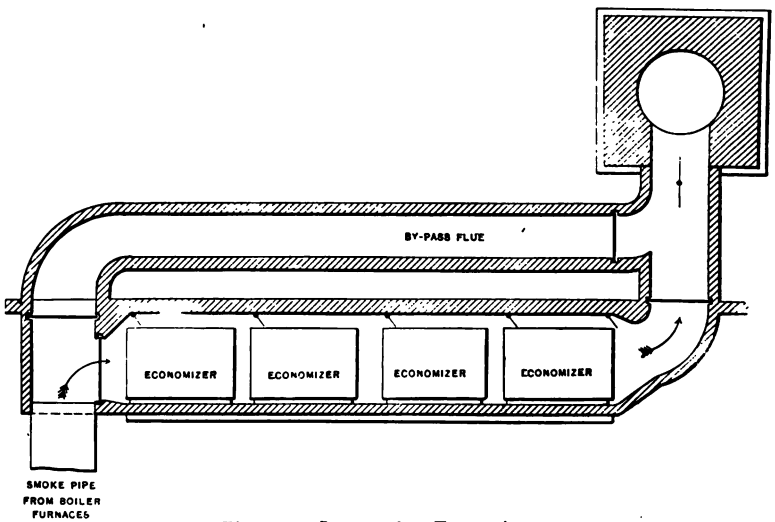



Fig. 141. Layout for Economizers.

the accumulation of soot removed by the scrapers, and which must be removed at frequent intervals.

*Location of Economizer.*—There are various ways of locating the economizer with relation to the boilers and chimney flues, depending upon the conditions to be met in each particular case. Fig. 141 shows a typical layout. Dampers and flues are provided so that the gases may be passed either through the economizer or turned directly into the chimney, in case it is desired to clean or repair the economizer at any time.

*Saving Effected by Economizers.*—One disadvantage in the use of an apparatus of this kind is that it reduces the chimney draft somewhat, owing to the friction of the gases in passing through it, and also to their reduced temperature. Provision must be made for this either by the use of mechanical draft or by providing a more powerful chimney than would otherwise be necessary.

The percentage of saving by the use of an economizer will depend on circumstances, but can be determined approximately by the general formula given for feed-water heaters. The average of nine tests, reported by Mr. William R. Roney in a paper read before the American Society of Mechanical Engineers showed

TABLE LXII.

APPROXIMATE SPACE REQUIRED FOR ECONOMIZERS.

| Number of tubes wide | Number of rows | Total length of economizer | Height over | | Dimensions inside walls | | | Area between tubes | | | External heating surface |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Gearing | Section | Without side dampers | With one side damper | With two side dampers | Without side dampers | With one side damper | With two side dampers | |
| | | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | | | | |
| 4 | 8 | 5 10 | 13 2½ | 10 2½ | 3 4 | 4 1 | 4 10 | 16.6 | 23.85 | 31.10 | 384 |
| 6 | 8 | 4 10 | " " | " " | 4 8 | 5 5 | 6 2 | 21.85 | 29.10 | 36.35 | 576 |
| 8 | 12 | 7 3 | " " | " " | 6 0 | 6 9 | 7 6 | 27.00 | 34.25 | 41.5 | 1152 |
| 10 | 16 | 9 8 | " " | " " | 7 4 | 8 1 | 8 10 | 32.25 | 39.50 | 46.75 | 1920 |

the rise in temperature of the feed water in passing through the economizer to be 140°, with a corresponding drop of 257° in the temperature of the furnace gases. The average saving in fuel for the same tests was 13.8 per cent. These results will of course vary somewhat in different cases.

While economizers are commonly used for the purpose of reducing the cost of fuel, they are often installed in connection with existing boiler plants for increasing the capacity. The addition of an economizer is, in effect, adding to the heating surface of

the boilers, although the additional surface cannot be rated on the same basis per square foot, owing to the reduced temperature of the gases to which it is exposed.

The percentage of saving in fuel by the use of an economizer may be taken as representing approximately, under average conditions, the increase in boiler capacity, should the same amount of fuel be burned as before the economizer was installed.

*Area of Heating Surface.*—It is customary under ordinary conditions to provide from 4½ to 5 square feet of heating surface in the economizer for each boiler horse power. Table LXII. will be found useful in determining the approximate space required for an economizer. This table gives only short lengths made up of 8 to 16 rows of tubes. In practice they are often made 60 or more rows deep. Any combination to give the required heating surface, flue area, etc., can be easily made up from the data given.

When it is desired to keep the resistance through the economizer as low as possible, the sections may be arranged in two groups with a by-pass flue between them, instead of placing them in a single row as in Fig. 141.

## CHAPTER XV.

### BOILER CORROSION.

A careful study of this subject based upon the experience of a large number of designing and operating engineers seems to indicate that the only satisfactory method of dealing with this important matter is to submit a sample of the feed water to a competent chemist for a careful analysis, and to obtain from him a suitable remedy for neutralizing the injurious effects of the impurities found. The leading boiler insurance companies do this free of charge for their clients. The great variety of impurities, and the varying quantities of each found in different localities, make it impossible to give definite solvent or precipitating solutions suitable for general use. Notwithstanding this fact, a brief review of the subject may be of some value, and serve as a guide in finding a remedy in special cases when the services of a chemist are not at hand.

Among the principal causes which tend to shorten the life of a boiler are corrosion and incrustation. The first of these is a chemical action; the second is mechanical. The quality of the feed water is an important factor in connection with these, for if it is impure it may injure the plates by corrosion, or it may deposit a sediment which, under certain conditions will form scale.

Corrosion may be both external and internal. The first is caused by exposure to the weather, moisture from the ground, or leakage from valves or fittings. Boilers which are set in brickwork are liable to external corrosion, as masonry tends to hold any moisture which comes in contact with the plates.

Internal corrosion may take place in various ways, such as general corrosion or wasting, pitting or honeycombing, and grooving.

General corrosion and pitting are due to the chemical action of the feed water, while grooving is the result of both chemical and mechanical action.

*General Corrosion* is difficult to detect, as it acts uniformly over a large surface, and is especially so when the rivet heads waste equally with the plates. The water may attack the plates at the water line only, or the action may in some cases be confined to a belt 6 or 8 inches wide at the water level. Often a seam will be in perfect condition, with the exception of a few rivets or small sections of the plates themselves. The stays or braces are usually weakened more rapidly than the shell plates.

This uncertain action depends principally upon the specific gravity of the corrosive agents, and the variation of temperature. The only reliable way to determine the amount of wasting is to drill through the plates, plugging them afterward. If the thickness is found to be reduced, the pressure carried by the boiler should be lowered in the same proportion.

*Pitting* is easily detected by examining the edges of the holes, from which the depth and extent are readily determined. Pitting occurs in the form of small patches varying from ½ to 10 or 12 inches in diameter. They are sometimes round and at other times have an irregular shape.

When the holes are small and close together it is called *honeycombing*. The reason for pitting is thought to be the difference in structure of the iron, otherwise corrosion would take place over the entire surface.

*Grooving.*—The cause of grooving is not always apparent, but is usually due to the springing of the plates, aided by local corrosion. This distortion of the plates is generally caused by improper staying, which allows them to spring back and forth with the varying steam pressure. Grooving usually occurs on the heads around the edge of the angle iron or in the root of the angle itself. Too rigid staying of the heads or too great a difference in the expansion of the tubes and shell, is almost always sure to cause grooving.

Internal grooving is often caused by excessive caulking, which injures the surface of the metal and exposes it unduly to the action of the corrosive elements in the feed water. Grooving has the appearance, sometimes, of a fine crack or fracture, and may extend into the metal for a considerable depth, even when it

shows only as a fine line at the surface. On account of the minuteness of the cracks they are hard to discover, and when once formed enlarge rapidly from the effect of any acidity in the feed water.

When possible the feed water supply should be changed as soon as internal corrosion is discovered. Such a change after corrosion has begun, will often prolong the life of the boiler.

*Incrustation.*—Hard scale or incrustation is formed by the accumulation of sediment from the feed water which is left in the boiler, either by evaporation or precipitation. Unless blown out at frequent intervals the sediment becomes hardened and forms scale. The amount of solid matter in average feed water varies from 20 to 40 grains per gallon; its injurious effect, however, does not depend so much upon the quantity as upon the nature of the substance.

Where proper care is given to blowing off the boiler, the presence of a certain amount of carbonate or chloride of lime would not be objectionable, while the same amount of other salts might cause much trouble.

*Impurities in Feed Water.*—The most common impurities found in feed water are the carbonates and sulphates of lime and magnesia. Chloride of magnesia is common in some localities, also salts of iron, sulphuric and carbonic acids and various organic substances.

The carbonates of lime and magnesia are held in solution by an excess of carbonic acid. Heating the water drives this off and causes the carbonates to be precipitated in the form of a light-gray mud. As the temperature of the water increases, this sediment becomes less soluble, until at the boiling point it is practically insoluble. If the carbonates are comparatively free from other impurities, such as oil, organic matter, etc., they may be washed out of the boiler after it has been allowed to cool.

Brackish water containing chloride of magnesia is injurious because when heated, the chloride decomposes, forming magnesia and hydrochloric acid, which rapidly corrodes the plates.

Sulphates of lime and magnesia are also precipitated when the temperature rises; precipitation being complete at about 290

degrees. This forms a hard scale which adheres firmly to the plates and tubes, while the carbonates are soft and granular, and of a grayish color. If the water contains iron the incrustation is given a reddish color.

When the condensation from exhaust steam is returned to the boilers, either from a heating system or a surface condenser, there is liable to be a small quantity of oil brought in even when special pains are taken to prevent it.

A deposit of oil mixed with other impurities is a poor conductor of heat, and overheating or burning of the plates is likely to follow.

*Overheating* is usually caused by a scale composed of the carbonates of lime and magnesia. These occur in the form of a light powder and are held in suspension or cover the surface of the water as a scum. When this becomes mixed with oil it offers considerable resistance to the rise of the bubbles of steam, and in some cases is sufficient to form a layer of steam next to the plates, which lifts the water away from them. As steam is a poor conductor of heat, the plates are liable to become seriously overheated when this occurs.

*Prevention of Incrustation.*—This may be accomplished in three ways: First, by precipitating the scale-forming substances before the feed water enters the boiler; second, by removing the sediment before it becomes hardened; and third, by removing the hard scale from the interior of the boiler by mechanical means.

*Purification of Feed Water.*—Water may be purified to a considerable extent by passing it through some form of open heater or purifier before it is fed into the boiler. The water in flowing over open trays in the presence of steam becomes heated, the carbonic acid is driven off by the rise in temperature, and the carbonates are precipitated in the trays and also upon the coke filter which is usually placed at the bottom of the heating chamber or receiver. A surface blow-off is provided in this type of purifier, so that organic matter or other impurities which rise to the surface may be blown off from time to time. The trays may be cleaned and replaced, but the filtering material should be changed at frequent intervals, or as often as may be found necessary.

The sulphates may be precipitated in a similar manner, but as a much higher temperature is required in this case it is necessary to use live steam at a pressure not less than 50 pounds.

*Purification by Solvents.*—When soda-ash is added to water containing sulphate of lime, the lime and soda change their acids and form sulphate of soda, which is soluble, and carbonate of lime, which is precipitated and can be washed out. The same action is also true of magnesia.

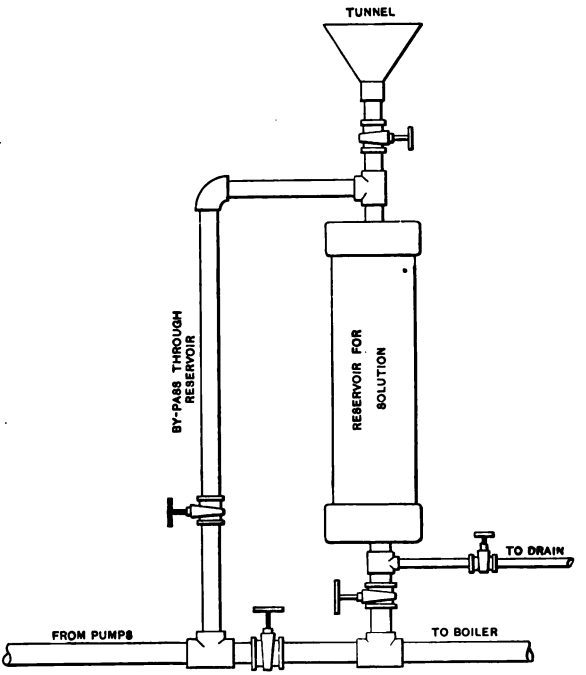



**Fig. 142. Device for Introducing Solvents.**

Water containing salts of iron and free sulphuric acid is successfully treated with a mixture of lime and soda-ash. Soda-ash is also used in water containing chloride of magnesia, which calls for an alkali to neutralize the hydrochloric acid which is set free when the water is heated.

Carbonic acid and oxygen may be removed by heating the feed water, and by the use of soda or slacked lime.

Water containing organic matter may be purified by precipitating with alum, and filtering.

Fig. 142 shows a device for introducing solvents into a boiler without passing the solution through the feed pump, which is objectionable as it is liable to destroy the packing. A section of 6-inch pipe about 30 inches long is used for a reservoir; suitable pipe connections and valves are provided for joining it to the feed pipe in the form of a by-pass. The reservoir is emptied through the drain cock, and then filled with the solvent solution, the valves are then set to pass the pump discharge through the reservoir, which carries the solution into the boiler with the feed.

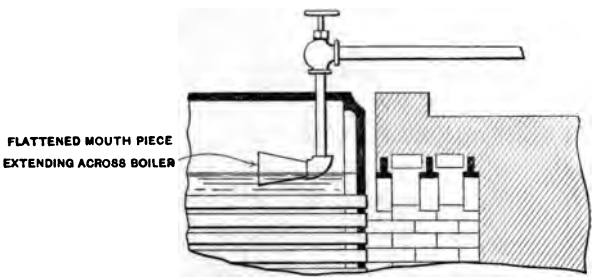



Fig. 143. Surface Blow-off.

*Removing Impurities from the Boiler.*—The easiest way to remove the impurities from a boiler after they have been deposited is by blowing off a portion of the water. Those which remain in suspension and float at the surface of the water may be discharged through the surface blow-off, a common form of which is shown in Fig. 143. The heavier sediment may be blown off from the lower part of the boiler through the usual pipes provided for this purpose.

*Removal of Scale.*—There are various ways of removing scale that has already formed. A safe method, but one which requires a good deal of time, is to chip it off with suitable tools. This, however, becomes difficult when the scale is hard or the construction of the boiler is complicated.

There are various forms of mechanical cleaners in use, designed both for water-tube and fire-tube boilers. The turbine cleaner

which is used for removing scale from the inside of the tubes consists of a revolving head, carrying a number of small toothed wheels for cutting the scale. The cutters are usually driven by a small water motor so arranged that the discharge passes into the tube and serves to wash away the chips from the cutters. When the scale is on the outside of the tube as in the case of a fire-tube boiler, a similar arrangement is used in which the cutters are replaced by small weights or hammers which strike against the inside of the tube in rapid succession and produce a vibration which is sufficient to loosen the scale from the outside.

Kerosene oil is used to some extent for the prevention and removal of scale. When used in the proper quantity it breaks up and loosens hard scale and prevents its formation. It is best introduced drop by drop by means of an oil feeder, and only enough should be used to produce the desired result, as an excess is likely to be carried over in the steam and to injure the interior surfaces of the engine cylinders.

No definite directions can be given for the use of the various remedies mentioned, and the necessary amount in any given case must be determined by trial, or better by a chemical analysis.

The formation of scale is less rapid in water-tube boilers than in fire-tube, owing to the more rapid circulation of the water in the former.

*Water Softening Plants.*—Although the various methods of purifying the feed water may be carried on to a large extent in the boilers themselves, it is now quite general in the case of large power plants to employ special apparatus for this purpose.

This method of purifying and softening the water does away to a large extent with the washing and cleaning of the boilers, except at long intervals, and results in a considerable saving in labor and repairs. Another saving is in the heat lost in the frequent blowing off of boilers for the removal of scale and mud.

In a general way the purification of feed water by this method consists in adding certain solutions of lime and soda and passing through suitable settling tanks and filters before feeding to the boilers.

## CHAPTER XVI.

### CARE AND MANAGEMENT OF STEAM BOILERS.

The best methods to be employed in the handling of any particular boiler plant can only be learned by experience. There are, however, certain rules and precautions which apply in a general way to all boilers, and a brief enumeration of these may be found of value, especially to young engineers and those of limited experience.

*Water Level.*—Before starting up the fires under a battery of boilers the fireman should first determine the water level in each. This should be done both by an inspection of the water-glasses and by trying the gauge cocks. The former is a quicker and more convenient method but may be misleading on account of the presence of dirt and foam. On the other hand, when the steam goes down in a boiler which is perfectly tight, a vacuum is formed which will prevent the water from appearing when the cock is opened, although the boiler may have a sufficient supply and the glass indicate the true level.

From this it is evident that neither the water glass nor the gauge cocks should be depended upon alone, but used to supplement each other. When a vacuum exists in the steam space as above described, the cocks should be opened and air admitted until the water flows from them freely before starting the fire. The admission of air will take place most rapidly through the upper cocks, provided they are above the water line; if not, the safety valve may be opened slightly.

After starting the fire, the gauge cocks or other outlet should be left open until steam appears. This allows the air to escape again as steam is formed to fill its place. After making sure of the true water line, the safety valve should be raised slightly, if it has not already been done, to see that it is in working order.

*Starting the Fire.*—In case the fires have been banked they should be shaken slightly to clear the grates of ashes and clinkers; the drafts should then be opened and the fire allowed to come up

somewhat before putting on fresh coal. If the fire has been allowed to go out, a new one may be started by throwing a thin layer of coal (if anthracite is used) over the entire grate, placing a piece of wood across the mouth of the furnace just inside the door, and laying other pieces at right angles to this with the ends resting upon it. This leaves a space under the wood for the admission of air. The wood is then covered with coal and a fire started with shavings, oily waste or any other combustible material at hand. The furnace doors should be kept closed until the wood is well ignited, as this arrangement causes the flames to pass over and through the coal more thoroughly. When the fire is well started it should be spread or pushed back evenly over the grates, after which the furnace doors may be closed, the draft doors opened, and fresh fuel added as required. In the case of bituminous coal, the wood should be placed directly upon the grates with all of the coal above it. When starting a fire under a cold boiler, it should be allowed to burn slowly at first so that all parts of the boiler and setting may be warmed up as evenly as possible, in order to avoid unequal expansion.

In the case of water-tube boilers the fire may be forced more at the beginning if necessary, owing to the smaller amount of water in the boiler and the greater distance of the joints from the hottest part of the fire. After the fire is once started, the method of adding more fuel depends upon the type of boiler, the kind of coal used, and the rate of combustion.

*Methods of Firing.*—There are three general methods of firing, known as "alternate" or "side" firing, "spreading" and "coking." In alternate firing, the coal is spread so as to cover one side of the furnace, leaving the other side bright; at the next firing the process is reversed. By this method the hydrocarbons given off by the fresh coal are burned by the hot gases from the incandescent coal, and only a part of the furnace is cooled when fresh fuel is added. This method of firing is especially adapted to cases where two furnaces lead to a common combustion chamber. Each furnace is fired regularly with a moderate amount of coal and the draft plates left open until the gas has burned off. Spreading is accomplished by firing small amounts of coal at short

intervals and spreading the same evenly over the entire surface of the fire. The coal should be delivered where needed and not be disturbed afterward. It is customary with this method to carry a somewhat thicker fire at the sides than at the center.

Very satisfactory results can be obtained in this way by using the proper kind of coal, as the fire may be kept in good condition at all times. Care should be taken to keep the furnace doors closed as much as possible during the process of firing in order to prevent the entrance of cold air. For a short time after coal has been added, and while gas is being given off, the draft plates in the furnace doors should be opened to admit air above the fire. These two systems are best adapted to anthracite coal, as it burns with comparatively little smoke.

When bituminous coal is used the coking system is to be preferred. In this case the coal is piled on the grate just inside the furnace door and is allowed to coke from 15 to 30 minutes, in order to distill the hydrocarbons. These gases are burned by admitting air through the draft plates. After the coking process, the mass is pushed back over the fire and fresh coal placed on the front of the grate. The air admitted cools the furnace somewhat and reduces the rate of evaporation, but the objection is not serious unless the boiler must be worked to its fullest capacity in order to furnish the required amount of steam. The proper thickness of fire must be determined by trial and will depend upon the grade of coal used and the available draft. In case of a strong draft and coarse coal the fire may be about a foot in thickness, but if the draft is weak or the coal fine, the thickness should not be more than four or five inches.

With forced draft, a thicker bed of coal must be carried in order to secure a high rate of combustion. With the same draft, bituminous coal may be fired more thickly than anthracite. After having determined by experiment the best thickness of fire to carry, it should always be kept the same. The rear of the grate should never be allowed to get bare, and air holes in the fire should be covered over as soon as formed. If it becomes necessary to force a boiler it may be done by firing smaller quantities of coal at shorter intervals. Never fire a large amount of coal and wait

for the pressure to rise, for the introduction of fresh fuel chills the furnace and retards combustion. Keep the grates free from clinkers and ashes, but do not clean oftener than necessary.

*Cleaning the Fire.*—When the fire is to be cleaned, the fireman should make sure that there is enough water and steam to last during the process. He then breaks up the clinkers with the slice bar and removes the ashes with the prick bar. Some firemen first push the fire to the rear and then clean the front of the grates, after which the coal is hauled forward and the rear of the grates cleaned. Others clean one side at a time instead of the front and the rear. In either case the fire should be allowed to burn down, but not so much that it cannot be easily brightened afterward. The dampers should be partly closed to reduce the amount of cold air admitted, and the work should be done as rapidly as possible in order to prevent too great a drop in the steam pressure.

*Banking the Fire.*—The best method of banking a fire will depend upon its condition, the length of time it is to be left, and also somewhat upon the experience of the fireman himself. The usual way is to first clean and then push back into a small space near the bridge wall. It is then covered with fresh coal to a thickness varying with the time the fire is to remain banked. The dampers should then be nearly closed, except as needed to carry off any small quantity of gas which may be formed, and the fire doors opened. When it is desired to start the fire again, the water level and steam pressure should be noted and the safety valve lifted slightly to see that it is in working order. The fire should then be cleaned and the ashes cleared from the grate by means of the prick bar. Coal may then be spread over the fire in a thin layer and the dampers opened.

*Blowing Off.*—The boiler should be emptied once in two weeks at least, and oftener if the feed water is impure. If the water is muddy or comes from a condenser and contains oil, five or six inches of water should be blown out daily, but never under a high pressure. A good time to do this is in the morning before starting up the fires or at noon when they can be allowed to die down slightly. When the water ceases to boil, much of the sediment,

which at other times is carried back and forth through the boiler by circulation, is deposited, usually in the coolest part of the boiler and a large part of it may then be blown out. Blowing off when there is a hot fire in the furnace does but little good unless the boiler is provided with a mud drum which is protected from the heat of the fire. The blow-off cocks should be carefully watched, so that any leaks which occur from this source may be quickly detected.

A boiler should never be emptied while hot, as this will cause any sediment or grease present to bake onto the heating surfaces.

*Boiler Feed.*—When possible, there should be two independent methods of feeding the boilers, and both of sufficient capacity to do the required work alone in case of a breakdown or repairs. Whatever the method of feeding the boilers, the apparatus used should work as smoothly and continuously as possible. Feed valves and checks should be tested and cleaned at frequent intervals.

*Sudden Shut-Down.*—If it becomes necessary to shut down the engine with a heavy fire under the boiler and steam at the blowing point, the drafts should be closed and the pump or injector started to keep the pressure from rising. The gauge should be closely watched until the safety valve lifts, to see that the latter works freely. If the safety valve is of sufficient size and in working order, the pressure cannot rise dangerously high with the pump or injector forcing cool water into the boiler.

*Low Water.*—In case of low water, cover the fire with wet ashes, or fresh coal, if the ashes are not at hand. Do not draw the fire until it has become so deadened that it can be done without increasing the heat. The safety valve should not be lifted at such a time, neither should cold water be fed into the boiler. The engine should be allowed to run until it stops, when the throttle valve may be closed. All conditions should be kept as uniform as possible until the fires can be checked and the boiler cooled down. In case of a fracture in the main steam pipe the water level is usually lowered very rapidly, and the first thing is to deaden the fires. If the rush of steam is not too great, and the gauge glass can be kept in view, the water level may often be

maintained by starting or increasing the speed of the pump.

Sudden leaks in the blow-off pipe or the melting of a fusible plug call for the same procedure as above.

*Prevention of Foaming and Priming.*—Foaming may be stopped sometimes by closing the throttle or stop valve, and keeping it closed until the water becomes quiet and shows a true level. If the foaming is caused by dirty water, it may be remedied by blowing off and adding fresh water. If the boiler primes, lower the water level.

*General Directions.*—Ashes should never be allowed to accumulate in the ash pit, for they may cause burning of the grates. In order to reduce the liability to such damage, some firemen make a practice of keeping a couple of inches of water in the ash pit.

The state of the water level in each boiler should be tested frequently by means of the gauge cocks, and fresh coal should never be fired without having sufficient water in the boiler. The water glass and gauge cocks should be kept in constant use, and the safety valve should be of ample size and kept in free working order. The pointer of the pressure gauge should stand at zero when there is no pressure upon the boiler, and if it fails to do so should be adjusted by comparison with a standard gauge. In case the pressure rises above the maximum point indicated by the gauge and the safety valve fails to blow off, the fires should be banked at once and the gauge and safety valve tested.

Fusible plugs should always be cleaned and scraped when the boiler is cleaned, or else they may fail to work when needed.

All parts of the boiler exposed to the fire should be kept clean and the tubes and flues swept as often as possible. The kind of fuel used will determine the frequency of cleaning, but it should be a rule never to allow a layer of soot or ashes to accumulate over $\frac{1}{16}$ of an inch in thickness. Manhole and handhole covers should be removed frequently for the inspection of interior surfaces, and before replacing them all finished bearing surfaces should be cleaned and oiled.

The outside of a boiler should be inspected at regular intervals, especially if the location is damp or there is much brickwork in the setting. Water should be kept from the exterior of a boiler

as much as possible in order to prevent corrosion. A careful lookout should be kept for cracks, blisters and defective joints, and if they appear, must be promptly attended to.

*Boiler Standing Idle.*—There are different opinions in regard to the best way of treating a boiler if it is to stand idle for some time. One method is to completely fill it with water in which a quantity of soda has been dissolved. Another way is to empty the boiler and thoroughly dry it; then place trays of quicklime in the bottom.